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EXPERIMENTAL AND THEORETICAL STUDIES OF SALT CREEP CLOSURE OF THE SPR BIG HILL SITE WELLS 106 THROUGH 110

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ABSTRACT

An experimental program was carried out in several Big Hill wells to determine whether salt creep closure is likely to result in borehole size being reduced to that of the outside diameters of hanging strings in the wells. Measured creep closures were sufficient to indicate the need for a small leaching program to ensure the boreholes would not close into contact with the hanging strings in the event that large scale leaching is not implemented in the near future. Theoretical calculations of creep closure using the "SANCHO" finite element computer program indicated radial and volumetric closures less than experimental values by factors of 4 and 2.5, respectively.

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INTRODUCTION

The Department of Energy (DOE) Strategic Petroleum Reserve (SPR) Big Hill site is planned to include 14 caverns having a total storage capacity of 140 million barrels of crude oil. The ten wells (106A and B through 110A and B) for the first five caverns (106 through 110) at Big Hill were drilled in 1983-1984. Before their completion, administration budget constraints dictated an indeterminate delay before salt leaching for oil storage caverns would begin. Because of salt creep closure of the wells, a question arose as to whether the hanging strings should be installed in the wells. It was considered possible that over an extended period of time, the boreholes would close to the extent that the salt would contact the hanging strings in the wells and prevent the beginning of leaching and would also prevent string removal. The hanging strings had already been procured and their installation in the wells was part of the existing well construction contract. A decision was made by the SPR Project Management Office (PMO) to install the hanging strings in the wells. Sandia National Laboratories (Sandia) was tasked by the SPR PMO with development and implementation of a program to ensure that the strings would remain free of the salt. This report describes the program and presents experimental and analytical results obtained during its implementation. Preliminary results of the program are described in Reference 1.

HISTORY AND BACKGROUND

The Big Hill SPR site, located in Jefferson County, Texas, was procured by the DOE as part of the planned expansion of the SPR crude oil storage capacity to 750 million barrels. The site, described in Reference 2, was planned to include 14 oil storage caverns, each having a 10 million barrel storage capacity. The site has a commercial history which dates back to 1901, but commercial oil production did not begin until 1949. Production wells on the southwest flank of the dome are currently being operated. The Union Oil Company operates two liquified-petroleum-gas (LPG) storage caverns on the northern part of the dome.

A layout of the site from Reference 3 is shown in Figure 1. Two wells were drilled for each planned cavern. Wells 106A and B through 110A and B were drilled between mid-1983 and early 1984. Eighteen additional wells (101A and B through 105A and B and 111A and B through 114A and B) were completed in late 1985. Cavern leaching was initially planned to begin in late 1985, but was delayed because of budget constraints. A preliminary analysis by Sandia and DOE indicated the risk of hanging string capture due to salt creep would not be great in the immediate future but that a creep monitoring program should be implemented to provide an early indication of possible string capture.

WELL DESCRIPTIONS

Figures 2 and 3 are sketches of the wells. The wells include: a 42-in conductor pipe driven to about a 120-ft depth; a 30-in casing cemented 15 to 100 ft into the caprock; a 20-in casing cemented to about a 1750-ft depth; and a 13 3/8-in production casing cemented to about a 2100-ft depth. The main difference between the "A" and "B" wells is in the configuration of the hanging strings. The "A" wells have a single 10 3/4-in casing hung to about a 2680-ft depth. The "B" wells have both 10 3/4 and 7-in hanging strings. The 7-in casing is hung to about a 4665-ft depth, slightly less than total well depth. The 10 3/4-in casing is hung to a depth of about 4365 ft, 300 ft above the 7-in casing. The hanging strings of the "A" and "B" wells are configured for the beginning of cavern leaching.

Start and completion dates for the wells are as shown below. Also shown are the number of days between well completion and the reference date of 10/01/83 used in Tables I and II.

Well Number	Start Date	Completion Date	Days From 10/01/83 To Well Completion
106A	11/24/83	02/01/84	122
106B	07/24/83	11/21/83	51
107A	07/05/83	11/18/83	48
107B	11/20/83	02/01/84	122
108A	06/17/83	10/23/83	22
108B	10/26/83	01/03/84	94
109A	06/10/83	09/09/83	-22
109B	09/14/83	11/27/83	57
110A	06/27/83	09/19/83	-12
110B	09/22/83	11/23/83	53

EXPERIMENTAL PROCEDURES

Pressure Buildup and Bleed Off

Shortly after the well pressure tests, Reference 4, the wells were shut in and the well pressures were allowed to increase as salt creep caused the wells to close. Pressures were allowed to increase to values near 500 psi, the pressure at which wellhead pressure relief valves were set to open. Following pressure buildup, brine was bled from the wellheads through a flexible hose into a volume calibrated container and measured. The first pressure cycles following the pressure tests included bleeding wellhead pressures to relatively low values (approaching atmospheric pressure), so as to increase the time between successive bleed offs. However, after about seven months, the volumes bled were generally limited to prevent wellhead pressures from dropping below about 300 psi.

Pressures were measured with 2000-psi and 600-psi dial type gauges read daily and periodically calibrated by on-site personnel of the mangagement and operations contractor (POSSI and Boeing Petroleum Services Inc., (BPSI)). On each wellhead, the 600-psi gauge was installed to measure pressure in the 13 3/8 x 10 3/4-in annulus. On the "B" wells, the 2000-psi gauges were installed to measure pressures in the 10 3/4 x 7-in annuli. On the "A" wells, without the 7-in hanging strings, the 2000-psi gauges were installed to measure pressures in the 10 3/4-in string.

Pressure buildup and bleed off measurements were continued from February 1984 to December 1985.

Borehole Caliper Logs

Caliper logs were obtained in the open salt sections of selected boreholes below the hanging strings in February 1984 and again in December 1985. The logs were obtained using the Micro Gage, Inc. O-arm caliper tool and were as follows:

Well Number	Februarv 1984	December 1985
106.4	Log	Log
106B	Log	Log
107A	Log	No Log
107B	Log	Log
108A	No Log	No Log
108B	No Log	Log
109A	No Log	No Log
109B	No Log	Log
110A	Log	Log
110B	Log	Log

The logging program was restricted in February 1984 by inaccessibility of the well pads because of extremely muddy roads. In December 1985, the program was restricted by funding limitations.

The 4-arm caliper tool was calibrated out of the well by use of 8 and 24-in gauge rings. The calibrations, which were repeated for several logs, indicated standard deviations in diameter of 0.3 to 0.4 in (standard deviations in radius of 0.15 to 0.20 in). These standard deviations correspond to 0.025 to 0.043-in pen displacement on the caliper record, and are probably less than twice the resolution of the log records. The average calibration results with the two gauge rings indicated instrument linearity of about 2 percent. During each actual well log, caliper readings were obtained in the lower portion of the hanging string just after obtaining results in the open borehole. Based on gauge ring calibration results, the average indicated inside diameter of the 7 in casing was 0.8 in too large and that for the 10 3/4-in casing was 0.25 in too small. Because of these inconsistencies, open borehole diameters were calculated using the assumption of caliper linearity and the known inside diameter of the hanging string as a one-point calibration. It is believed that this procedure reduced possible borehole caliper errors due to effects on the instrument of pressure, temperature, and time.

Borehole Temperature Measurements

Temperature logs were run in selected wells in February 1984 and December 1985 using a temperature tool developed by Southwest Research Institute for Sandia. For the February 1984 logs, the tool, which transmits digital signals to the surface, was run on a Schlumberger 7-conductor wireline. Subsequent to these logs, the tool was modified by Southwest Research Institute to allow it to be used with either a single-conductor or a 7-conductor wireline. For the December 1985 logs, the tool was run on a Micro Gage single conductor wireline. The temperature logs included the following:

Well Number	Februarv 1984	December 1985
106A	Log	No Log
106B	No Log	Log
107A	Log	No Log
110A	Log	Log

Similar to the caliper logging program, the temperature logging program was restricted in February 1984 because of inaccessibility of the well pads and in December 1985 because of funding limitations.

FINITE ELEMENT ANALYSIS

Finite Element Program

Calculations of borehole closure due to salt creep were made by use of the finite element computer program named SANCHO. SANCHO is a finite element structural computer program developed from HONDO II (Reference 5) specifically for calculating the creep closure of underground cavities in rock salt (Reference 6). Uses of the program to date are documented in References 7 through 12. SANCHO is a large strain, large deformation program containing a variety of constitutive models which provide the relationship between stress and strain. The solution strategy is based on dynamic relaxation wherein an acceleration term is added to the equilibrium equation converting the static problem into a dynamic one in pseudo time to iteratively obtain an equilibrium solution. An instantaneous "optimum" damping value is computed internally at each time step and used to follow the "transient" response out in pseudo time until a solution is converged. Satisfaction of global equilibrium at each load step is used to control the convergence of the iterative procedure. The magnitudes of the residual force vector and the applied load vector are compared to determine when global equilibrium has been reached.

The material model for creep is a power law model for secondary (steady state) creep. The creep model is integrated "semi-analytically" by a technique which has been shown to be accurate for any strain increment. This method has no stability or time step restrictions as are usually associated with classical Euler integration. The only restriction is that the strain rate should be approximately constant during the time step.

Material Properties

At the time this study was initiated, salt from the Big Hill site had not been tested to obtain elastic or creep material properties. The creep model parameters derived from compression and extensive (triaxial) testing of salt core from the West Hackberry site (Reference 13) were used in this study. After the initiation of this study, salt cores from the Big Hill site were evaluated (References 14 and 15). Creep properties of the Big Hill salt were very similar to those of West Hackberry salt and thus, there appeared to be little reason for repeating the finite element analysis with adjusted salt properties.

As mentioned previously, the program uses a secondary (steady state) creep model of the form:

$$\dot{\bar{e}} = A \exp(-Q/RT)(\bar{\sigma})^n \qquad (1)$$

where,

$\dot{\bar{e}}$ = effective secondary creep strain rate,

A = laboratory determined constant,

Q = activation energy,

R = universal gas constant,

T = temperature in degrees Kelvin,

$\bar{\sigma}$ = effective stress, and

n = stress exponent.

$\bar{e}$ and $\bar{\sigma}$ are scalar quantities that are proportional to the second invariants of the deviatoric strain and stress tensors, respectively.

The laboratory determined creep coefficients for West Hackberry salt, together with the elastic constants obtained from quasi-static tests, Reference 16, are as follows:

A = 4.915E-11 $1/(\text{day})(\text{psi})^n$

Q = 13.12 kcal/(mole K)

n = 4.73

Youngs Modulus = 5.57E6 psi

Poissons Ratio = 0.30

Finite Element Model

A borehole that is 15 in in diameter and 2700-ft deep (below the cemented casing) is difficult to model with a single typical finite element mesh because of the gross difference in dimensions in the two directions. One method used in the past (Reference 17) includes a finite element model of a thin horizontal slice such as that shown in Figure 4. The model is two-dimensional axisymmetric with brine pressure on the left end and constant lithostatic pressure on the right end. The top and bottom of the model are constrained to prevent vertical movement but allow horizontal movement. A single borehole is represented by four of these models, each of which corresponds to a different depth. The small thermal mass of the borehole fluid in relation to the surrounding salt results in the borehole arriving at thermal equilibrium with the surrounding salt relatively quick, and with little thermal influence on the surrounding formation. It is therefore assumed that the borehole temperature is very close to the salt temperature and that this temperature is constant with distance from the borehole at any depth. Depths of the four models, together with corresponding temperatures from well logs included herein, are listed below. Also listed are borehole loading pressures for the wells filled with saturated brine and with wellheads open to the atmosphere. Lithostatic pressure is assumed to increase at the rate of 1 psi per foot of depth.

Depth (ft)	Temperature (°F)	Borehole Pressure (psi)	Lithostatic Pressure (psi)
2115	108	1102	2115
3000	118	1563	3000
4000	133	2084	4000
4700	144	2449	4700

As mentioned earlier, pressures in the wells were cycled over several months by shutting in the wells, allowing salt creep to cause an increase in pressure, and then relieving this pressure by removing brine from the well. For three of the wells, 106B, 107B and 109A, piecewise linear approximations of measured wellhead pressures were added to the above borehole pressures to obtain a more accurate representation of boundary conditions in the borehole for the finite element calculations during the early part of the test period.

In addition, calculations were made for 2000 days for a typical well assuming constant wellhead pressures of 0, 200, and 400 psi. The pressure of 400 psi is near the average wellhead pressure of 387 psi during the major (later) part of the tests when the ranges of allowable pressure cycles were minimized.

EXPERIMENTAL RESULTS

Pressure Measurements

Pressures measured in the wells from the times the wells were completed until December 1985 are included in Figures 5 through 9. The pressure spike at about 130 to 150 days corresponds to the well tests at wellhead pressures of 800 psi.

Approximations of the pressure increase rates on each cycle with pressures between about 300 and 500 psi were obtained by linear regressions of pressure versus time data. Results of these linear regressions are summarized in Table I.

The sharp drop in pressure following each period of pressure buildup resulted from the removal of brine from the wellhead. A summary of the pressure drops during bleed offs, together with measured volumes of brine bled, is presented in Table II.

It is noted that brine which included gas accumulated at the wellheads of wells 106A, 106B, 107A, 107B and 108B during each pressure buildup and bleed off cycle. The presence of gas was indicated by boiling and foaming of brine after it was removed from the well. No gas was noted in the other wells.

Caliper Logs

Borehole diameter measurements from the caliper logs are summarized in Table III. The table includes borehole diameters calculated as discussed previously by assuming linearity of the caliper tool and by using the known inside diameter of the hanging string just above its bottom as a reference. The table also includes changes in open hole radius between the February 1984 and the December 1985 logs, and a radial clearance between the open hole diameter and a collar on the 10 3/4-in hanging string.

Borehole Temperature Logs .

Results of the individual borehole temperature logs are presented in Figures 10 through 12. Figure 11 includes a complete log for well 107A and a section of the log which was repeated because of a slightly different temperature profile than noted for wells 106A and 110A in Figure 10. The repeated section confirmed the initial log. The log for well 106B in December 1985, Figure 12A, includes a temperature discontinuity at about the 1100-ft depth. There was no reason to suspect a problem with the temperature tool, and no explanation of the discontinuity is available.

Figure 13 is an overlay of all the temperature logs of Figures 10 through 12. Data of this figure indicate somewhat different temperature profiles at depths less than 1100 ft, and possibly a slight cooling between February 1984 and December 1985 at these depths. However, at greater depths, the total variation of temperature at a given depth is less than 2 F.

THEORETICAL RESULTS

Finite element calculations were made for four to six months during the first year following completion of wells 106B, 107B, and 109A using approximations of measured wellhead pressures to define borehole pressures (boundary conditions) for the model. These calculations were made for the time period during which wellhead pressures were allowed to fluctuate over large ranges and were terminated before the beginning of pressure cycling over the approximate 300-psi to 500-psi range shown in Figures 5, 6, and 8. The measured wellhead pressure versus time histories were approximated by a sequential series of linear segments.

Curves of radial closure versus days from well completion for wells 106B, 107B, and 109A, from the finite element calculations, are given in the "B" graphs of Figures 14, 15, and 16, respectively. The "C" graph in each figure gives the variation with time of well volume corresponding to the calculated radial closure. Volume changes were calculated by assuming a linear variation of radius between depths for the finite element calculations. An initial borehole diameter of 15 in was assumed for these calculations. The closure curves show a significant increase in closure with borehole depth. The radial closure essentially doubles for each 1000 ft of increased depth.

Wellhead pressures were calculated using the initial well volumes, the change in well volumes due to salt creep, and the compressibility of brine in the wells. These calculated pressures are included with the measured wellhead pressures in the "A" graphs of Figures 14 through 16. The calculated pressures for wells 106B and 107B increase more slowly than measured values and at the end of the four-month calculation periods are lower than measured values by a factor of about two to three. Results are similar for well 109A but at the end of the six-month calculation period are below measured values by a factor of about 1.5.

Additional finite element calculations of radial closure were made for a longer period of time (2000 days) with wellhead pressures of 0, 200, and 400 psi. These pressures almost cover the range of pressures between those with an open wellhead and maximum values which may be allowed without danger of opening pressure relief valves set for 500 psi. Results are included in Figure 17. Well volumes corresponding to the radial closures of Figure 17 are summarized in Figure 18.

DISCUSSION OF RESULTS

Experimental results of pressure increase rates, volumes of brine lost from the wells, and radial borehole closures over the 22-month test period are summarized in Table IV. It is noted that data of Table IV are separated according to whether gas was detected at the wellheads at the times of brine bleed off. The total volume of brine removed and lost from the wells includes an estimate of leakage at an average pressure of 387 psi, based on results of well leak tests at 800 psi from Reference 4. Estimates of leak rates at 387 psi were made by use of the following equation from Reference 18.

$$U \propto \left(\frac{dP/dX}{\rho \nu^n} \right)^{\frac{1}{2-n}} \tag{2}$$

where

U = flow velocity in leak path,

dP/dX = pressure gradient in leak path,

ρ = fluid density,

ν = kinematic viscosity, and,

n = an exponent with a value between 0 and 1 which depends on conditions of the flow and leak path.

With brine at a given temperature, leakage from a specific depth in the well, y_1, and discharge from the leak path to a global hydrostatic pressure at some lesser depth, y_d, equation 2 can be re-written;

$$\frac{U_2}{U_1} = \left(\frac{\Delta P_2}{\Delta P_1} \right)^{\frac{1}{2-n}} = \left(\frac{P_2 + 0.52 \times y_1 - g_h \times y_d}{P_1 + 0.52 \times y_1 - g_h \times y_d} \right)^{\frac{1}{2-n}} \tag{3}$$

where

g_h = hydrostatic gradient from surface to depth of leak path discharge (a reasonable value of 0.46 psi/ft is assumed),

subscript 1 refers to conditions at an 800-psi well-head pressure during leak test, and

subscript 2 refers to conditions at an average well-head pressure of 387 psi during the current test.

A leak rate ratio, U_2/U_1, was calculated assuming the case of a leak from the casing seat depth of 2100 ft to a global hydrostatic pressure at top of salt at a depth of 1600 ft. The value of this ratio used in Table IV was 0.722, the average of values from Equation (3) assuming values of n-0 and n=1.

It is noted in Table IV that pressure increase rates and volumes of brine bled from "gassy" wells were roughly double values for "non-gassy" wells. The increased rate of pressure buildup is consistent with gas accumulation at the wellhead. The increased volume of brine removal required to reduce pressures by given amounts is consistent with higher well elasticities, which would result from communication of brine in the well with a gas formation. It is noted, however, that during the leak tests of Reference 4, a trace amount of gas was noted in only one well, and no significant differences in well elasticities were noted between the wells now found to be "gassy" and those that are "non-gassy".

The finite element calculations indicated a well volume reduction of 21 cubic feet during 22 months (669 days) at a wellhead pressure of 400 psi, Figure 18. This is a factor of 2.5 less than values of total brine lost from the "non-gassy" wells over the same time span at about the same pressure level, Table IV. There is no clear explanation of the discrepancy, though similar discrepancies between measured and calculated volume changes have been noted in analyses of results from drifts mined in bedded rock salt, Reference 19. It is not logical to try to compare the finite element results with experimental results for the "gassy" wells.

The finite element volume change results of Figure 18 were also used to calculate pressure increase rates at times between 500 and 660 days, corresponding to about the last six months during which pressures were measured. Calculated pressure increase rates were 3.5 psi/day with zero wellhead brine pressure, 1.9 psi/day with 200-psi wellhead brine pressure, and 1.3 psi/day with 400-psi wellhead brine pressure. The calculated value at 400 psi compares with an average experimental value of 2.6 psi/day for the non-gassy wells (Table IV) which was obtained at about the same pressure level (average pressure of 387 psi). Thus, finite element calculated pressure increase results are a factor of 2 less than experimental results. This is generally consistent with the finite element volume change being a factor of 2.5 less than experimental.

The caliper log results of Table III indicate a large range of measured reduction of borehole radius over the 22-month test period. The average radius reduction indicated is 0.31 ±0.22 in. The finite element results for the same time period at 400-psi wellhead pressure indicate a radius reduction of 0.08 in, a factor of four lower than the average measured value. The fact that this discrepancy between calculated and measured radial closure is about twice as great as that between calculated and measured volume decrease rates and pressure increase rates is believed likely to be due to inaccuracies in borehole caliper log results. The previously mentioned standard deviation of the caliper tool gauge ring calibrations is about half the average indicated radius reduction of 0.31 in. The discrepancy between gauge ring and downhole calibration in the hanging strings is considerably greater. The factor of two to four between measured and calculated results, though certainly greater than desired, represents a considerably improved confidence in computational capability over that of five years ago when almost no experimental data for direct comparison were available.

It is of interest to note in Figure 17C that the calculated radial closure at the 4700-ft depth after 2000 days (66 months) is 0.16 in, about twice that noted above after 22 months.

Triaxial creep experiments on cylindrical specimens of several natural rock salts have shown that the primary-creep stage of the test ends at an approximate creep strain range of 0.5 to 3.0 percent, depending on the confining pressure, the temperature, and other test conditions, References 12 and 13. The finite element calculation with a constant wellhead pressure of 400 psi was used to obtain an estimate of the variation with time of creep strain at the borehole boundary. This should give some indication of the amount of time from borehole completion during which primary creep will influence the wellhead pressure rise. Because of the significant increase in closure with depth (Figures 14 to 16), the closures at 4000 and 4700-ft depths dominate the volumetric response of the borehole and consequently the wellhead pressure. The calculated creep strain at the borehole boundary at the 4700-ft depth reached 0.5 percent 250 days after well completion and 1.0 percent 1125 days after well completion. At the 4000-ft depth, the calculated strain at the borehole boundary reached 0.5 percent after 1150 days. The calculated strains at the 2115 and 3000-ft depths were well below 0.5 percent at the end of the calculation (2000 days). The calculated borehole pressure increase rates are a factor of approximately two less than measured values. Since pressure change is proportional to volume change, the calculated volume of the borehole should also be a factor of two less than the actual volume. It can be shown that for small displacements the borehole volume is a linear function of displacement at the borehole wall so a factor of two also applies to wall displacement. An analysis of the strain tensor shows that for an axisymmetric borehole, a factor of two increase in creep displacement will also result in a factor of two increase in creep strain. Thus, the factor of two between measured and calculated pressure increase rates is also expected to apply to the difference between actual and calculated strain rates. Using this factor of two and the nonlinear creep strain versus time curves (not included herein), creep strain at the borehole boundary at the 4700-ft depth reached 0.5 percent after 100 days and 1.0 percent after 450 days. A similar exercise for the 4000-ft depth shows creep strain reaching 0.5 percent after 430 days. These results indicate that primary creep will have an impact on borehole performance for at least 100 to 450 days. It will probably be much longer since primary creep may continue through 3 percent creep strain. Also, the calculated strains in the primary creep range at the 2115 and 3000-ft depths are indicated for thousands of days. However, the contribution of this portion of the borehole to volume loss and pressure rise will probably not be detectable.

The measured pressures for wells 106B, 107B, and 109A during the first four to six months of the tests and the calculated pressures are combined on individual graphs in Figure 19. Time in the graphs is the number of days from completion of the individual wells. For the measured results, Figure 19A, the initial pressure increase rate for well 107B is greater than that for well 106B, which is in turn greater than that for well 109A. This decrease in initial pressure increase rate coincides with increasing time from well completion. It is logical that primary creep, which decreases with time, is probably responsible for some of this behavior. The higher initial pressure increase rates for wells 106B and 107B are probably also due, in part, to gas accumulation at the wellheads, which was not present for well 109A. Primary creep would be expected to cause wellhead pressure buildup at a rate which decreases with time. The general trend of pressure buildup results in Table I appears to be just the opposite; that is, toward a pressure buildup rate which increases with time. Thus, the pressure data indicate the absence of significant primary creep effects during this latter part of the test.

While there is much variation between measured values of radial closure of the wells, the results of Table III indicate some uncomfortably small clearances between the boreholes and collars on 10 3/4-in casings in the "B" wells which are hung to depths of about 4365 ft. Consequently, a recommendation has been made by Sandia to DOE for a small leaching program of all "B" wells with 10 3/4-in hanging strings to the 4365-ft depth, Reference 20. The recommended program includes injection of raw water at a rate of 100 gallons per minute for 8 hours. The program is designed to increase the radial clearance at the bottom of the 10 3/4-in casing by about 3 in, an amount which is expected to avoid salt "capture" of the 10 3/4-in casing for a period of about ten years.

CONCLUSIONS

An experimental program was carried out with several Big Hill wells to determine whether salt creep closure is likely to result in salt capture of hanging strings. Measured creep closures were sufficient to indicate the need for a small leaching program to insure no capture of 10 3/4-in strings hung to near the bottom of the wells in the event that large-scale leaching is not implemented in the near future. Theoretical calculations of creep closure using the "SANCHO" finite element computer program indicated radial and volumetric creep closures less than experimental values by factors of 4 and 2.5, respectively.

Table I. Summary of Wellhead Pressure Buildup Results During Shut In

A. Wells 106A and 106B

Well Number	Beginning Date	Days From Oct 1, 1983: Beginning Of Shut In	Days From Oct 1, 1983: End Of Shut In	Constants For Equations Of Pressure Build Up From Linear Regressions: Intercept psig	Constants For Equations Of Pressure Build Up From Linear Regressions: Slope psi/day	Average Pressure psi	Average Slope psi/day
BH106A	12-Sep-a4	347	375	338	3.218	383.1	
	15-Oct-84	380	425	357	2.498	413.2	
	04-Dec-84	430	463	356	3.138	407.0	
	lo-Jan-a5	467	496	327	3.673	380.3	
	13-Feb-85	501	521	331	4.395	375.0	
	08-Mar-85	524	542	338	3.847	372.6	
	29-Mar-85	545	566	335	3.830	375.2	
	24-Apr-85	571	587	338	3.837	368.7	
	15-May-85	592	611	336	3.893	373.0	
	06-Jun-85	614	682	329	1.417	377.2	
	16-Aug-a5	685	711	358	3.004	397.1	
	16-Sep-a5	716	740	359	2.795	392.5	
	16-Oct-85	746	768	362	2.581	390.4	
	13-Nov-85	774	788	356	3.652	381.6	3.270
BH106B	12-Sep-a4	347	375	344	3.636	394.9	
	21-Nov-84	417	437	347	3.845	385.5	
	15-Oct-84	380	412	360	3.137	410.2	
	14-Dec-84	440	471	351	3.116	399.3	
	la-Jan-85	475	496	340	4.384	386.0	
	13-Feb-85	501	521	332	5.072	382.7	
	08-Mar-85	524	542	346	4.525	386.7	
	29-Mar-85	545	564	341	4.623	384.9	
	22-Apr-85	569	507	353	4.413	392.7	
	15-May-85	592	611	337	4.872	383.3	
	06-Jun-a5	614	634	322	4.989	371.9	
	Ol-Jul-a5	639	661	327	4.776	379.5	
	26-Jul-a5	664	682	343	4.540	383.9	
	16-Aug-a5	685	705	336	4.563	381.6	
	lo-sep-a5	710	726	346	4.846	384.8	
	01-Oct-85	731	747	334	5.033	374.3	
	22-Oct-85	752	768	337	4.441	372.5	
	13-Nov-a5	774	787	347	4.478	376.1	4.405

Table I Summary of Wellhead Pressure Buildup Results During Shut In

B. Wells 107A and 1078

Well Number	Beginning Date	Days From Oct 1, 1983: Beginning Of Shut In	Days From Oct 1, 1983: End Of Shut In	Constants For Equations Of Pressure Build Up From Linear Regressions: Intercept psig	Constants For Equations Of Pressure Build Up From Linear Regressions: Slope psi/day	Average Pressure psi	Average Slope psi/day
BH107A	21-Nov-84	427	437	347	4.541	392.4	
	14-Dec-84	440	463	349	4.289	398.3	
	lo-Jan-85	467	485	339	5.128	385.2	
	31-Jan-85	488	502	328	6.302	372.1	
	20-Feb-85	508	524	362	4.749	400.0	
	13-Mar-85	529	541	348	7.060	390.4	
	28-Mar-85	544	559	331	5.915	375.5	
	17-Apr-85	564	577	346	5.960	384.7	
	06-Jun-85	614	673	319	5.374	370.1	
	28-Jun-85	636	657	334	4.978	386.3	
	24-Jul-85	662	677	367	4.931	404.0	
	13-Aug-85	682	695	376	4.785	407.1	
	29-Aug-85	698	711	367	5.208	400.9	
	29-Oct-85	759	768	349	5.274	372.7	
	13-Nov-85	774	787	356	4.648	386.2	5.277
BH107B	03-Oct-84	368	375	352	7.216	377.3	
	15-Oct-84	380	394	361	6.383	405.7	
	Ol-Nov-84	397	412	347	6.524	395.9	
	12-Dec-84	438	450	365	6.725	405.4	
	28-Dec-84	454	471	361	5.088	404.2	
	18-Jan-85	475	485	347	8.000	387.0	
	31-Jan-85	488	502	329	7.453	381.2	
	20-Feb-85	508	521	382	5.426	417.3	
	08-Mar-85	524	541	346	6.551	401.7	
	28-Mar-85	544	559	343	6.493	391.7	
	17-Apr-85	564	577	356	6.266	396.7	
	06-Jun-85	614	633	323	5.989	379.9	
	28-Jun-85	636	653	345	5.599	392.6	
	18-Jul-85	656	670	365	4.992	399.9	
	06-Aug-85	675	682	373	6.116	394.4	
	16-Aug-85	685	695	345	6.833	379.2	
	29-Aug-85	698	711	356	5.238	390.0	
	16-Sep-85	716	726	365	6.061	395.3	
	01-Oct-85	731	740	352	7.744	386.8	
	16-Oct-85	746	754	376	6.481	401.9	
	29-Oct-85	759	768	360	6.037	387.2	
	13-Nov-85	774	7RJ	367	6.431	395.9	
	27-Nov-85	788	800	360	5.833	395.0	6.325

Table I. Summary of Wellhead Pressure Buildup Results During Shut In

C. Wells 108A and 108B

		Days From Oct 1, 1983		Constants For Equations Of Pressure Build Up From Linear Regressions			
Well Number	Beginning Date	Beginning Of Shut In	End Of Shut. In	Intercept psig	Slope psi/day	Average Pressure psi	Average Slope psi/day
BH108A	10-Oct-84	375	437	375	1.133	409.5	
	14-Dec-84	440	485	363	1.501	396.8	
	04-Feb-85	492	527	348	1.719	378.1	
	14-Mar-85	530	566	342	2.282	383.1	
	24-Apr-85	571	586	345	2.893	366.7	
	14-May-85	591	632	342	2.175	386.6	
	27-Jun-85	635	677	354	2.097	398.0	
	13-Aug-85	682	705	374	2.386	401.4	
	10-Sep-85	710	728	367	2.759	391.8	
	01-Oct-85	731	740	336	5.701	361.7	2.463
BH108B	12-Sep-84	347	375	341	3.944	396.2	
	15-Oct-84	380	404	361	3.511	403.1	
	14-Nov-84	410	433	367	3.696	409.5	
	12-Dec-84	438	463	362	3.923	411.0	
	lo-Jan-85	467	487	346	4.278	388.8	
	04-Feb-85	492	502	351	5.929	380.6	
	20-Feb-85	508	527	365	3.781	400.9	
	14-Mar-85	530	542	343	5.000	373.0	
	29-Mar-85	545	566	332	4.431	378.5	
	15-May-85	592	612	338	4.628	384.3	
	07-Jun-85	615	632	340	4.634	379.4	
	27-Jun-85	635	657	336	4.275	383.0	
	13-Aug-85	682	695	369	4.400	397.6	
	29-Aug-85	698	711	361	3.929	386.5	
	16-Sap-85	716	726	367	3.628	385.1	
	01-Oct-85	731	747	343	4.753	381.0	
	22-Oct-85	752	762	366	3.189	381.9	
	06-Nov-85	767	783	347	4.556	383.4	4.249

Table I Summary of Wellhead Pressure Buildup Results During Shut In

D. Wells 109A, 109B, 110A, and 110B

Well Number	Beginning Date	Days From Oct 1, 1383: Beginning Of Shut In	Days From Oct 1, 1383: End Of Shut In	Constants For Equations Of Pressure Build Up From Linear Regressions: Intercept psig	Constants For Equations Of Pressure Build Up From Linear Regressions: Slope psi/day	Average Pressure psi	Average Slope psi/day
BH109A	12-Dec-84	438	486	353	1.714	394.1	
	04-Feb-85	492	527	346	2.374	387.5	
	06-Aug-85	675	711	354	2.360	396.5	
	16-Sep-85	716	740	356	2.821	389.9	
	16-Oct-85	746	775	358	2.486	394.0	
	19-Nov-85	780	804	357	2.781	390.4	2.423
BH109B	06-Nov-84	402	436	350	2.243	388.1	
	13-Dec-84	439	480	351	2.051	393.0	
	29-Jan-85	486	502	356	2.696	377.6	
	20-Feb-85	508	527	353	3.209	383.5	
	14-Mar-85	530	564	332	2.963	382.4	
	22-Apr-85	569	579	351	3.378	367.9	
	24-Jul-85	662	695	344	2.464	304.7	
	29-Aug-85	698	726	352	2.200	382.8	
	01-Oct-85	731	754	335	3.375	373.8	
	29-Oct-85	759	783	330	3.301	369.6	
	27-Nov-85	788	802	325	3.612	350.3	2.863
BH110A	13-Dec-84	439	480	354	1.871	392.4	
	29-Jan-85	406	521	348	2.762	396.3	
	08-Mar-85	524	542	345	3.281	374.5	
	29-Mar-85	545	577	334	2.879	380.1	
	06-Aug-85	675	705	355	2.178	387.7	
	10-Sep-85	710	740	346	2.264	380.0	
	16-Oct-85	746	775	346	2.356	380.2	
	19-Nov-85	780	801	343	2.714	371.5	2.538
BH110B	13-Dec-84	439	480	346	2.315	393.5	
	29-Jan-85	486	502	340	3.813	370.5	
	20-Feb-85	508	542	362	2.010	396.2	
	29-Mar-85	545	577	337	3.053	385.8	
	06-Aug-85	675	711	340	2.145	386.6	
	16-Sep-85	716	740	341	2.543	371.5	
	16-Oct-85	746	775	335	2.327	368.7	
	19-Nov-85	780	801	329	2.799	350.4	2.626

Table II. Summary of Bleed Off Results

A. Wells 106A and 106B

Well Number	Date	Days From Oct 1, 1983	Pressure psig Before Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH106A	28-FEB-84	150							
	25-APR-84	208	380	60	40	0.125	0.092		
	03-JUL-84	277	440	40	45	0.113	0.087		
	10-SEP-84	346	435	300	12	0.089	0.023		
	11-OCT-84	377	430	300	15	0.115	0.065		
	OB-JAN-85	463	455	300	17	0.110	0.026		
	11-FEB-85	498	440	295	15	0.103	0.057		
	06-MAR-85	520	415	295	12	0.100	0.073		
	27-MAR-85	541	410	300	11	0.100	0.070		
	22-APR-85	567	420	305	12	0.104	0.062		
	13-MAY-85	588	405	300	20	0.190	0.127		
	04-JUN-85	610	410	280	15	0.115	0.091		
	14-AUG-85	682	440	320	12	0.100	0.022		
	12-SEP-85	711	435	315	12	0.100	0.055		
	11-OCT-85	740	430	310	12	0.100	0.055		
	OB-NOV-85	768	420	305	12	0.104	0.057	0.064	262
BH106B	28-FEB-84	150							
	25-APR-84	208	370	60	35	0.113	0.081		
	03-JUL-84	277	460	20	45	0.102	0.087		
	10-SEP-84	346	455	300	15	0.097	0.029		
	11-OCT-84	377	445	300	13	0.090	0.056		
	19-NOV-84	416	450	300	14	0.093	0.048		
	12-DEC-84	439	430	300	12	0.092	0.070		
	16-JAN-85	471	450	295	13	0.084	0.054		
	11-FEB-85	498	440	290	15	0.100	0.074		
	06-MAR-85	520	430	300	12	0.092	0.073		
	27-MAR-85	541	430	300	12	0.092	0.076		
	18-APR-85	563	430	300	13	0.100	0.079		
	13-MAY-85	588	440	300	20	0.143	0.107		
	04-JUN-85	610	430	275	15	0.097	0.091		
	24-JUL-85	661	430	300	12	0.092	0.031		
	14-AUG-85	682	425	295	32	0.092	0.076		
	06-SEP-85	705	440	300	12	0.086	0.070		
	07-NOV-85	768	410	285	12	0.096	0.025		
	04-DEC-85	794	420	320	12	0.120	0.062	0.066	294

Table II. Summary of Bleed Off Results

B. Well 107A

Well Number	Date	Days From Oct 1, 1983	Pressure psig Before Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH107A	26-FEB-84	148							
	25-APR-84	208	485	35	55	0.122	0.123		
	11-JUN-84	255	460	65	45	0.114	0.128		
	18-JUL-84	292	440	20	50	0.119	0.181		
	10-SEP-84	346	475	300	17	0.097	0.042		
	19-NOV-84	416	460	300	17	0.106	0.032		
	12-DEC-84	439	440	300	15	0.107	0.087		
	08-JAN-85	463	445	300	16	0.110	0.089		
	30-JAN-85	485	445	300	15	0.103	0.091		
	15-FEB-85	502	420	300	17	0.142	0.134		
	11-MAR-85	525	450	300	18	0.120	0.105		
	27-MAR-85	541	420	300	15	0.125	0.125		
	15-APR-85	560	430	305	15	0.120	0.106		
	01-MAY-85	576	420	40	48	0.126	0.401		
	04-JUN-85	610	400	285	15	0.130	0.059		
	26-JUN-85	633	420	300	15	0.125	0.087		
	22-JUL-85	659	445	310	12	0.089	0.062		
	09-AUG-85	677	440	325	12	0.104	0.089		
	27-AUG-85	695	440	340	12	0.120	0.089		
	12-SEP-85	711	435	330	12	0.114	0.100		
	08-NOV-85	768	400	300	12	0.120	0.028		
	04-DEC-85	794	435	350	12	0.141	0.062	0.106	445

Table II. Summary of Bleed Off Results

C. Well 1078

Well Number	Date	Days From Oct 1, 1983	Pressure psig Before Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH107B	26-FEB-84	148							
	25-APR-84	208	485	35	55	0.122	0.123		
	01-JUN-84	245	460	50	45	0.110	0.163		
	03-JUL-84	277	460	20	50	0.114	0.209		
	08-AUG-84	313	450	10	50	0.114	0.186		
	10-SEP-84	346	410	300	11	0.100	0.045		
	01-OCT-84	367	440	300	14	0.100	0.089		
	11-OCT-84	377	410	300	12	0.109	0.160		
	19-NOV-84	416	450	300	15	0.100	0.051		
	10-DEC-84	437	415	300	16	0.139	0.102		
	26-DEC-84	450	445	295	15	0.100	0.154		
	16-JAN-85	471	455	300	16	0.103	0.102		
	30-JAN-85	485	435	300	15	0.111	0.143		
	15-FEB-85	502	440	300	15	0.107	0.118		
	06-MAR-85	520	450	290	18	0.113	0.134		
	26-MAR-85	540	450	290	18	0.113	0.120		
	15-APR-85	560	450	300	18	0.120	0.120		
	01-MAY-85	576	440	20	60	0.143	0.501		
	04-JUN-85	610	430	275	15	0.097	0.059		
	26-JUN-85	633	435	300	15	0.111	0.087		
	16-JUN-85	653	440	325	12	0.104	0.080		
	02-AUG-85	670	450	320	12	0.092	0.094		
	14-AUG-85	682	420	310	32	0.109	0.134		
	26-AUG-85	695	425	310	12	0.104	0.123		
	12-SEP-85	711	420	310	12	0.109	0.100		
	11-OCT-85	740	425	310	12	0.104	0.055		
	08-NOV-85	768	420	320	12	0.120	0.057		
	25-NOV-85	785	440	320	12	0.100	0.094	0.126	569

Table II. Summary of Bleed Off Results

D. Wells 108A and 108B

Well Number	Date	Days From Oct 1, 1983	Pressure psig Before Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH108A	11-FEB-84	134							
	05-OCT-84	372	460	300	20	0.125	0.011		
	12-DEC-84	439	440	295	15	0.103	0.030		
	31-JAN-85	486	425	295	15	0.115	0.043		
	12-MAR-85	526	410	285	15	0.120	0.050		
	22-APR-85	567	425	300	12	0.096	0.039		
	13-MAY-85	588	395	300	21	0.221	0.134		
	25-JUN-85	632	425	300	15	0.120	0.046		
	09-AUG-85	677	435	320	12	0.104	0.036		
	06-SEP-85	705	430	320	12	0.109	0.057	0.049	137
BH108B	11-FEB-84	134							
	25-APR-84	208	385	45	50	0.147	0.090		
	10-JUL-84	284	455	32	60	0.142	0.106		
	10-SEP-84	346	445	300	16	0.110	0.035		
	11-OCT-84	377	450	300	18	0.120	0.078		
	09-NOV-84	406	445	300	16	0.110	0.074		
	10-DEC-84	437	440	300	18	0.129	0.078		
	08-JAN-85	463	460	295	18	0.109	0.093		
	31-JAN-85	486	445	300	18	0.124	0.105		
	15-FEB-85	502	410	295	13	0.113	0.109		
	12-MAR-85	526	440	305	20	0.148	0.111		
	27-MAR-85	541	400	295	14	0.133	0.125		
	22-APR-85	567	435	300	17	0.126	0.087		
	13-MAY-85	588	425	300	17	0.136	0.108		
	05-JUN-85	611	430	300	15	0.115	0.087		
	25-JUN-85	632	415	300	15	0.130	0.096		
	22-JUL-85	659	430	340	12	0.133	0.059		
	09-AUG-85	677	425	320	12	0.114	0.089		
	27-AUG-85	695	425	325	12	0.120	0.089		
	12-SEP-85	711	415	320	12	0.126	0.100		
	25-NOV-85	785	425	320	12	0.114	0.022	0.087	385

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Table II. Summary of Bleed Off Results

E. Wells 109A and 109B

Well Number	Date	Days From Oct 1, 1983	Pressure psig Before Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH109A	12-FEB-84	135							
	10-JUL-84	284	420	30	45	0.115	0.040		
	10-DEC-84	437	435	295	15	0.107	0.013		
	31-JAN-85	486	475	300	15	0.111	0.041		
	12-MAR-85	526	425	180	30	0.122	0.100		
	03-MAY-85	578	475	35	45	0.115	0.116		
	02-AUG-85	670	450	310	15	0.107	0.022		
	12-SEP-85	711	435	320	12	0.104	0.039		
	11-OCT-85	740	375	305	12	0.171	0.055		
	15-NOV-85	775	435	300	12	0.089	0.046	0.052	201
BH109B	12-FEB-84	135							
	10-JUL-84	284	435	34	45	0.112	0.040		
	11-DEC-84	438	430	300	13	0.100	0.011		
	25-JAN-85	480	440	300	15	0.107	0.048		
	15-FEB-85	502	410	300	11	0.100	0.067		
	12-MAR-85	526	415	285	15	0.115	0.084		
	18-APR-85	563	430	300	13	0.100	0.047		
	03-MAY-85	578	425	35	45	0.115	0.401		
	22-JUL-85	659	425	330	12	0.126	0.020		
	27-AUG-85	695	425	305	12	0.100	8.045		
	25-NOV-85	785	440	320	12	0.100	0.018	0.078	193

Table II. Summary of Bleed Off Results

F. Wells 110A and 110B

Well Number	Date	Days From Oct 1, 1983	Pressure psig Refore Bleed	Pressure psig After Bleed	Gallons Removed	gal/psi	ft^3/day	Average ft^3/day	Total Gallons Removed
BH110A	13-FEB-84	136							
	08-AUG-84	313	435	20	50	0.120	0.038		
	11-DEC-84	438	450	300	15	0.100	0.016		
	25-JAN-85	480	435	300	13	0.096	0.041		
	27-MAR-85	541	400	300	11	0.110	0.024		
	01-MAY-85	576	420	30	48	0.123	0.183		
	02-AUG-85	670	430	320	12	0.109	0.017		
	06-SEP-85	705	415	300	12	0.104	0.046		
	11-OCT-85	740	415	275	12	0.086	0.046		
	15-NOV-85	775	420	305	12	0.104	0.046	0.051	185
BH110B	13-FEB-84	136							
	08-AUG-84	313	425	25	50	0.125	0.038		
	11-DEC-84	438	450	300	15	0.100	0.016		
	25-JAN-85	480	450	300	17	0.113	0.054		
	15-FEB-85	502	410	300	10	0.091	0.061		
	06-MAR-85	520	440	295	15	0.103	0.111		
	27-MAR-85	541	440	295	10	0.069	0.064		
	01-MAY-85	576	430	35	45	0.114	0.172		
	02-AUG-85	670	425	310	12	0.104	0.017		
	12-SEP-85	711	420	305	12	0.104	0.039		
	11-OCT-85	740	405	300	12	0.114	0.055		
	15-NOV-85	775	410	300	12	0.109	0.046	0.061	210

Table III. Summary of Caliper Log Results

Well Number	Caliper Depth, ft	X-Y Caliper Record Pen Displacement, in: Logs Of FEB-84 X-Value	Logs Of FEB-84 Y-Value	Logs Of DEC-85 X-Value	Logs Of DEC-85 Y-Value	Average Diameter, in: FEB-84 Log	Average Diameter, in: DEC-85 Log	Radius Change Indicated By Two Logs, in	Corresponding Radial Clearance Of 11.75-in OD 10 3/4 Collar, in
106A	* 2650	0.79	0.82		0.810				
	2 100	1.21	1.29		1.240	15.602	15.385	-0.108	
	4600	1.21	1.28		1.180	15.540	14 64 1	-0.450	1.445
106B	** 4650	0.61	0.58	0.550	0.660				0.077
	4700	1.18	1.13	1.070	1.150	12.573	11.904	-0.314	
107B	** 4650	0.56	0.62	0.520	0.600				0.757
	4700	1.24	1.25	1.140	1.150	13.656	13.264	-0.196	
108B	** 4650			0.590	0.640				0.720
	4700			1.240	1.250		13.206		
109B	** 4650			0.560	0.650				0.390
	4700			1.140	1.200		12.531		
110A	* 2650	0.07	0.84	0.870	0.900				
	2700	1.24	1.24	1.210	1.410	14.580	14.861	0.141	
	4600	1.26	1.24	1.170	1.390	14.695	14.519	-0.088	1.384
110B	** 4650	0.57	0.57	0.540	0.650				0.646
	4700	1.24	1.25	1.160	1.230	14.101	13.043	-0.529	
Average Of Values At 4600 **And 4700-ft Depths**						14.105	13.301	-0.315	0.775

* Caliper Tool Inside And Near Bottom Of 10 3/4-in Suspended Caslng **With** 10.050 ID

** Caliper Tool Inside And Near Bottom Of ?-in **Suspended** Casing With **6.456-h** ID

TABLE IV. Condensed Overall Summary of Experimental Results.

Well Number	Gassy?	(1) Measured Pressure Increase Rate psi/day	(2) Total Brine Bled ft^3	(3) Estimate of Brine Leaked at Ave Press of 387 psi ft^3	Col (2) + Col (3) Total Brine Lost-Sum of Measured Volume Bled and Estimated Leak ft^3	(4) Radius Change at 4100-ft Depth Caliper in
106A	Yes	3.270	35.0	39.3	74.3	-0.450
106B	Yes	4.405	39.3	53.4	92.7	-0.314
107A	Yes	5.277	59.5	75.9	05.4	
107B	Yes	6.325	76.1	31.1	101.2	-0.196
108B	Yes	4.249	51.5	23.7	75.2	
	Average	4.705	52.3	34.7	87.0	-0.320
108A	No	2.463	18.3	66.0	84.3	
109A	NO	2.423	76.9	18.5	45.4	
109B	No	2.863	25.8	23.7	49.5	
110A	No	2.538	74.7	71.5	46.2	-0.088
110B	No	2.626	28.1	9.6	37.7	-0.529
	Average	2.583	74.8	27.9	52.6	-0.309

Over 22-Month Test Period (columns 2–4)

(1) Average from Table I

(2) From Table II

(3) Based on Measured Leak Rate at 800 psi Wellhead Pressure from Reference 4
Adjusted to Average Wellhead Pressure of 387 psi

(4) From Table III

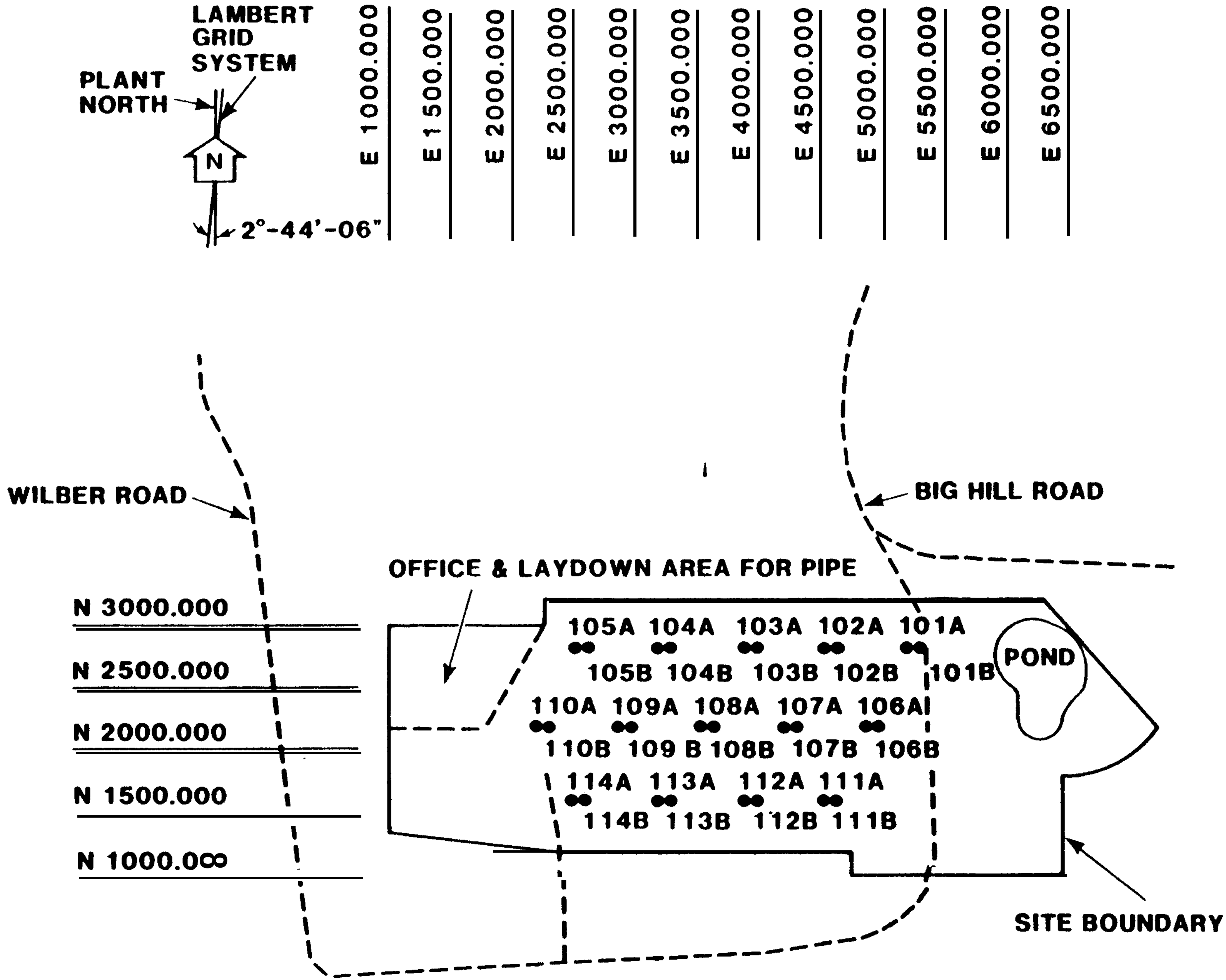
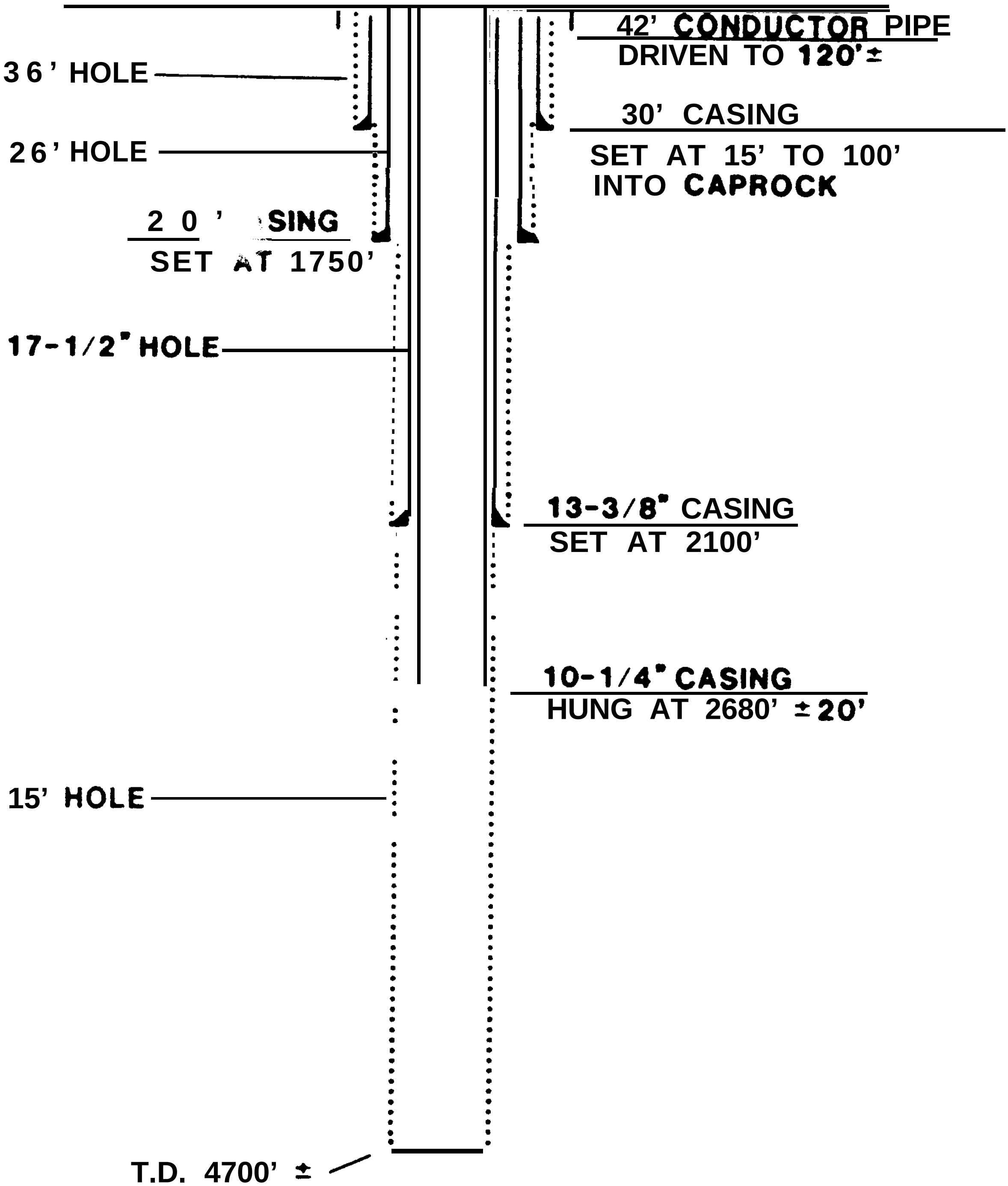


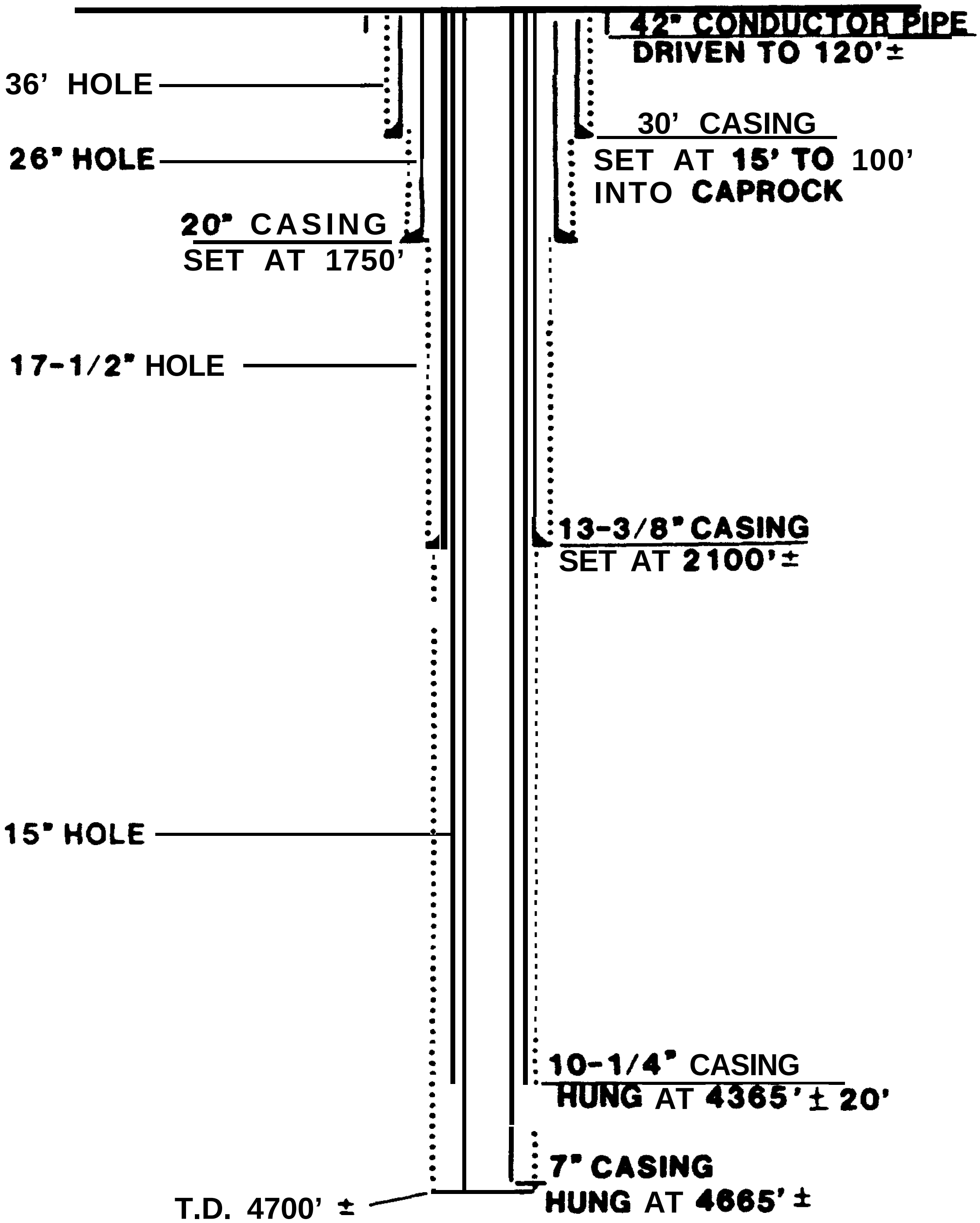
Figure 1 Big Hill Strategic Petroleum Reserve Site Layout, Jefferson County, Texas. (Grid system based on "Plant" coordinates.)



NOTES:

1. ALL DEPTHS ARE APPROXIMATE.
2. HOLE DIAMETERS SHOWN ARE MINIMUM HOLE SIZES.

Figure 2. Design Sketch of "A" Wells.



NOTES:

1. ALL DEPTHS ARE APPROXIMATE.
2. HOLE DIAMETERS SHOWN ARE MINIMUM HOLE SIZES.

Figure 3. Design Sketch of "B" Wells.

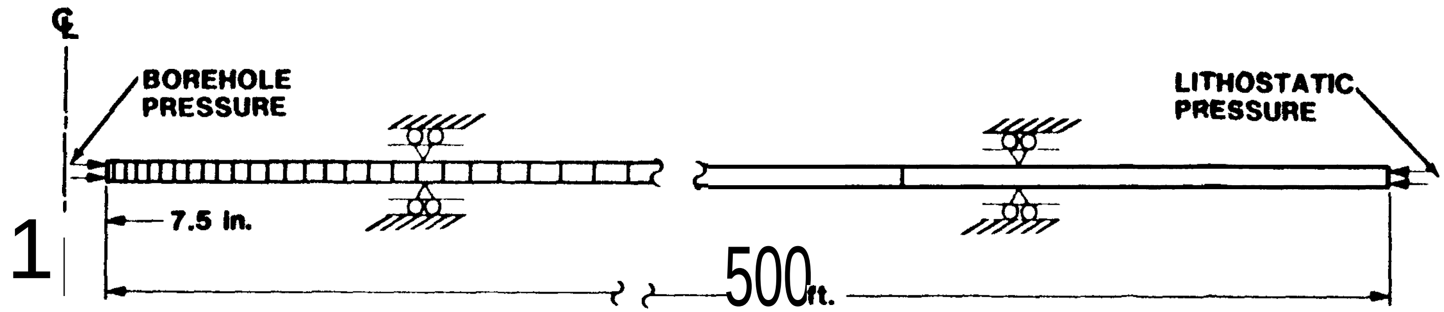
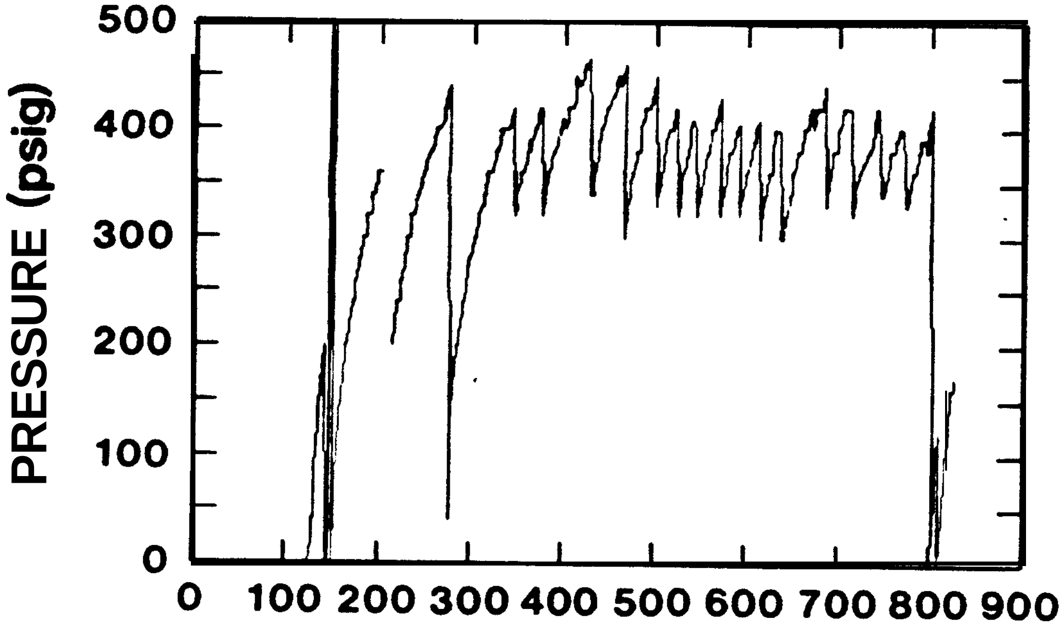
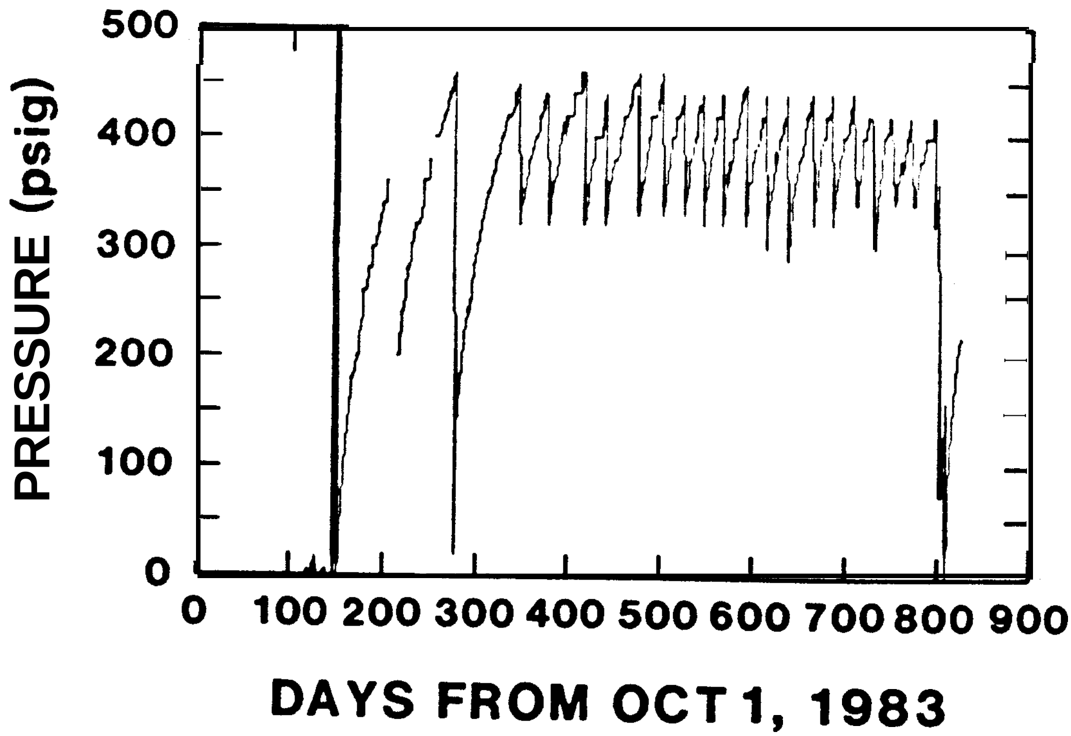


Figure 4. Two-Dimensional Axisymmetric Finite Element Model of Borehole Horizontal Slice.



A. Well 106A.



B. Well 106B.

Figure 5. Pressure-Time Histories for Big Hill Wells 106A and 106B. (Wellhead pressures measured in 13 3/8 x 10 3/4-inch annulus.)

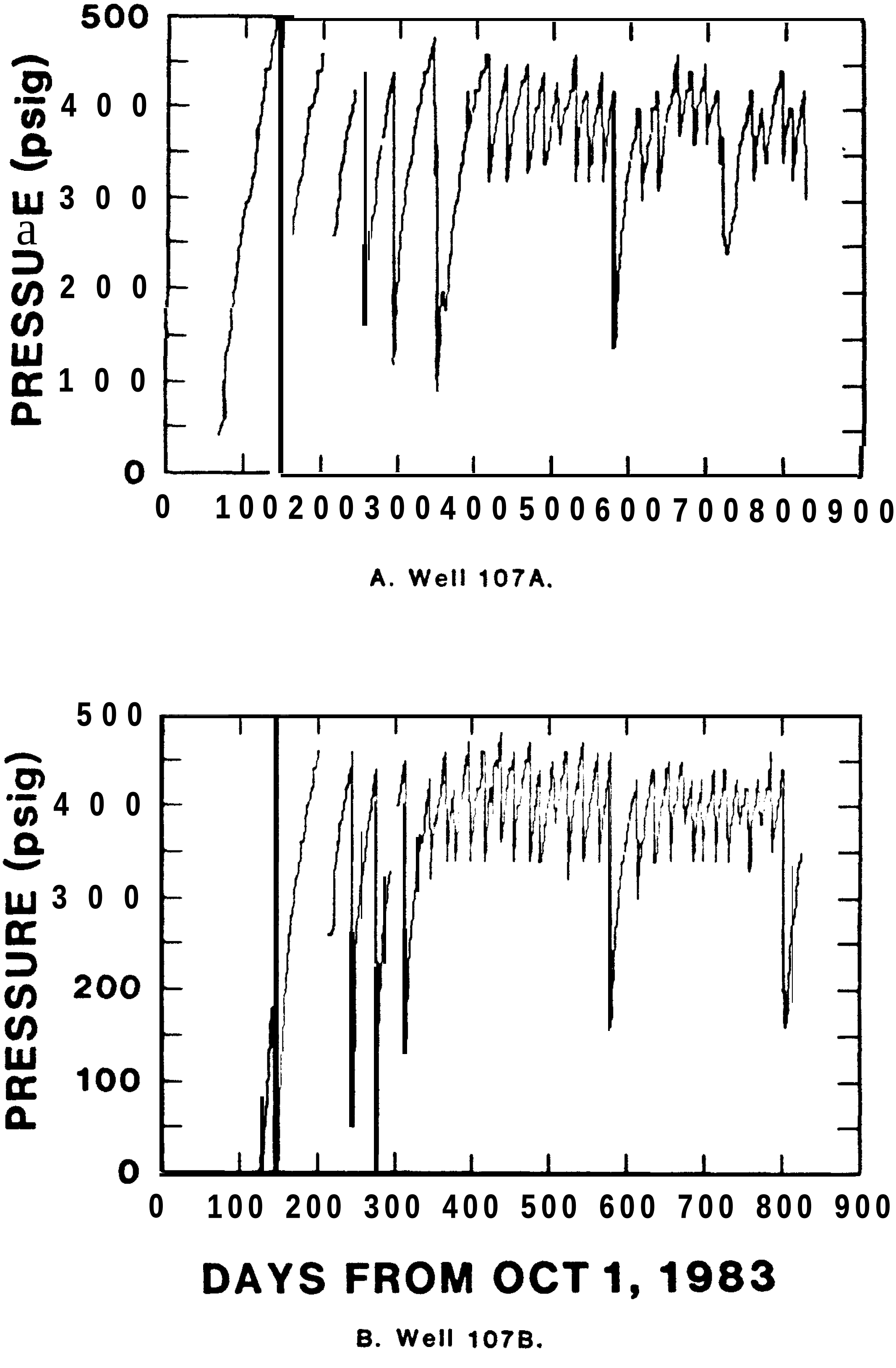
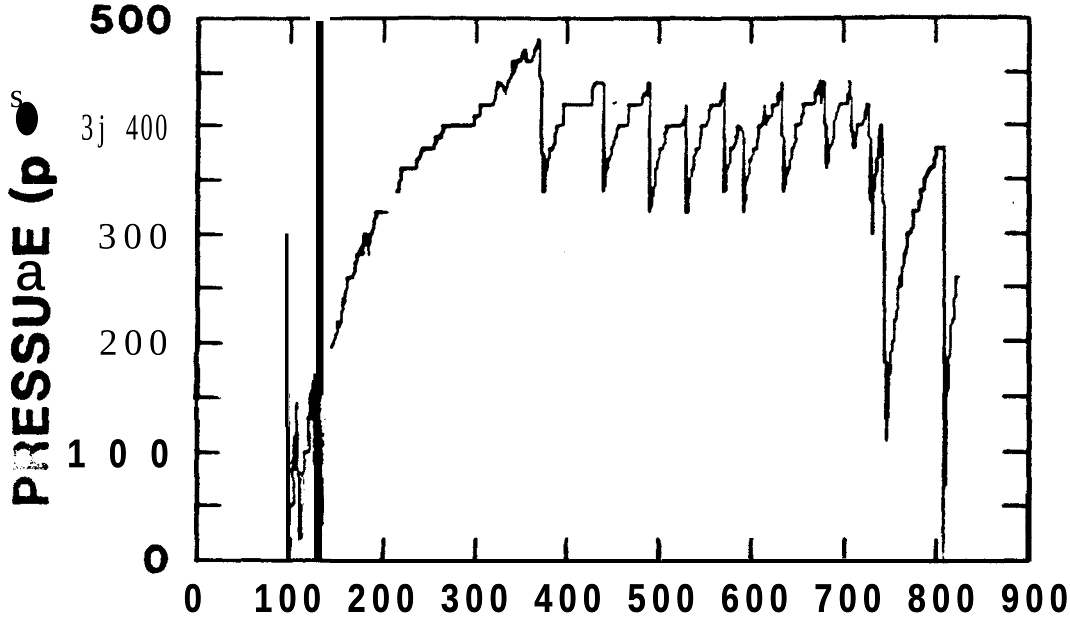
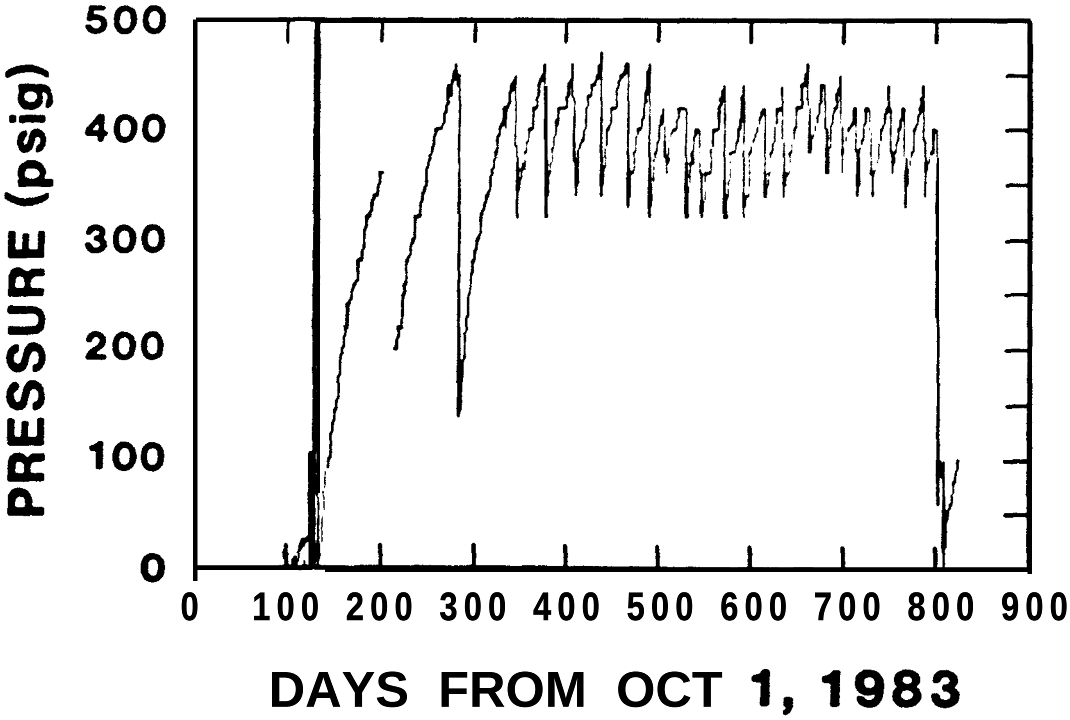


Figure 6. Pressure-Time Histories for Big Hill Wells 107A and 107B. (Wellhead pressures measured in 13 3/8 x 10 3/4-inch annulus.)

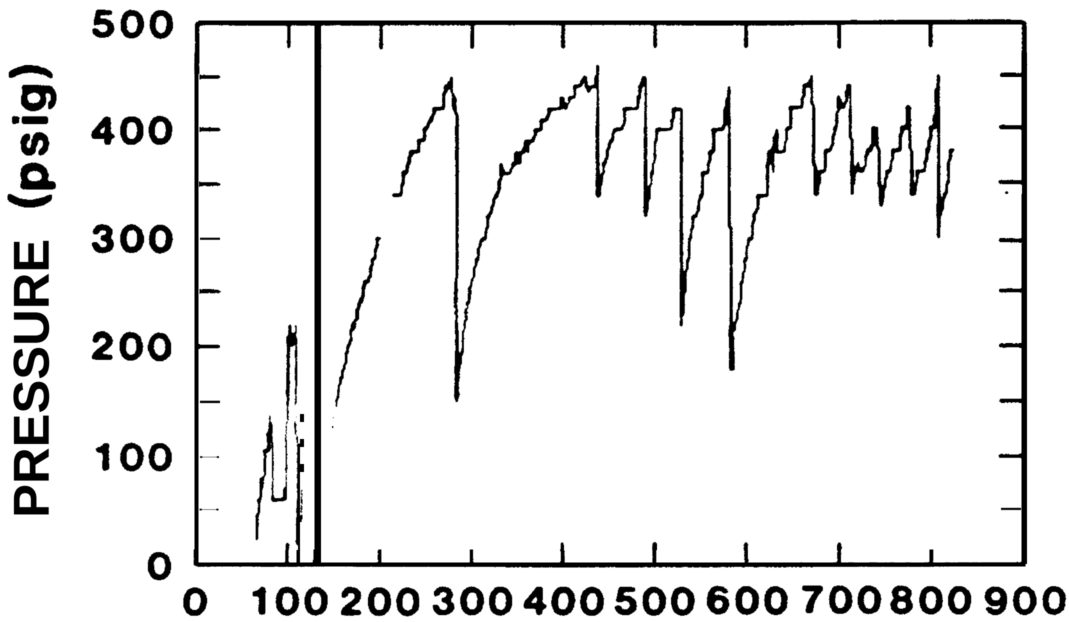


A. Well 108A.

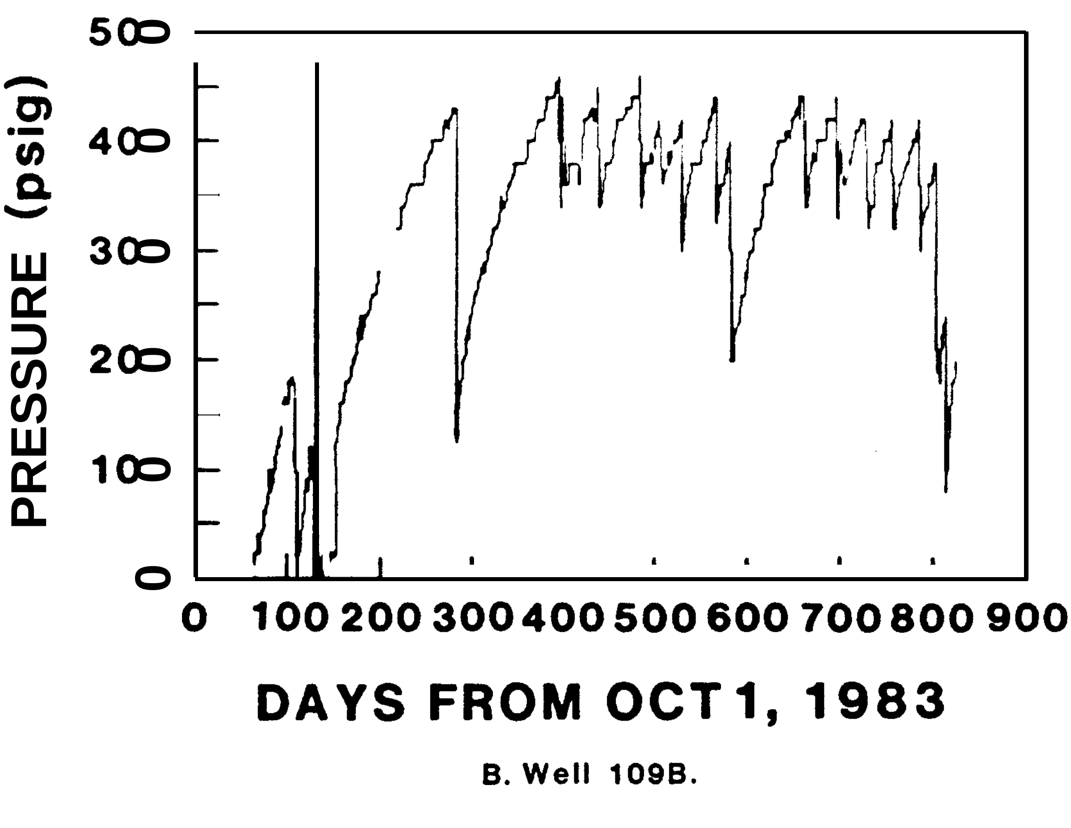


B. Well 108B.

Figure 7. Pressure-Time Histories for Big Hill Wells 108A and 108B. (Wellhead pressures measured in 13 3/8 x 10 3/4-inch annulus.)

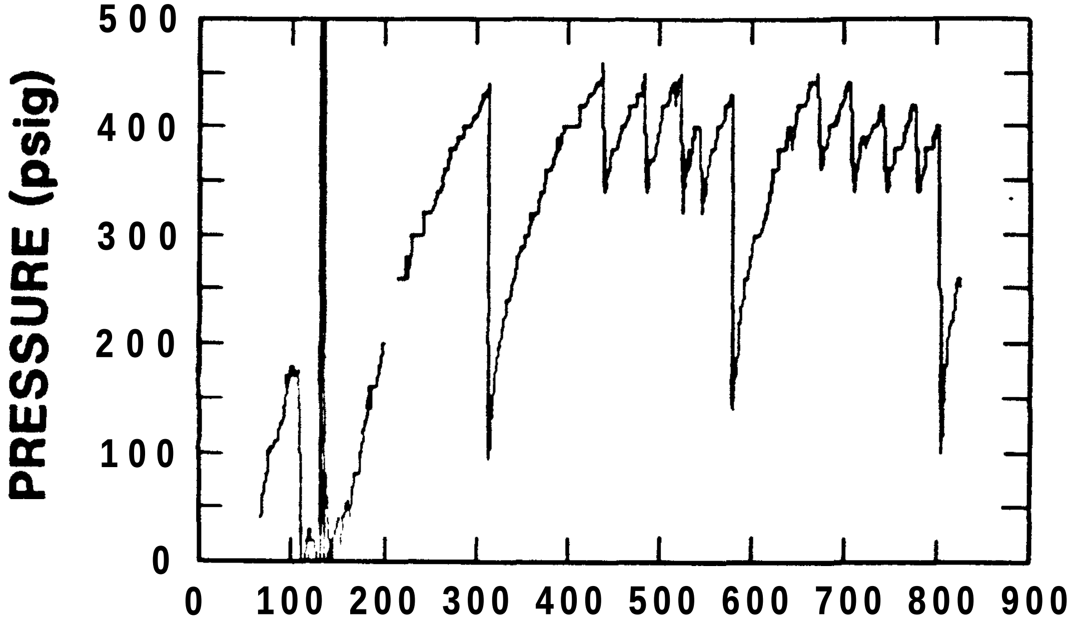


A. Well 109A.

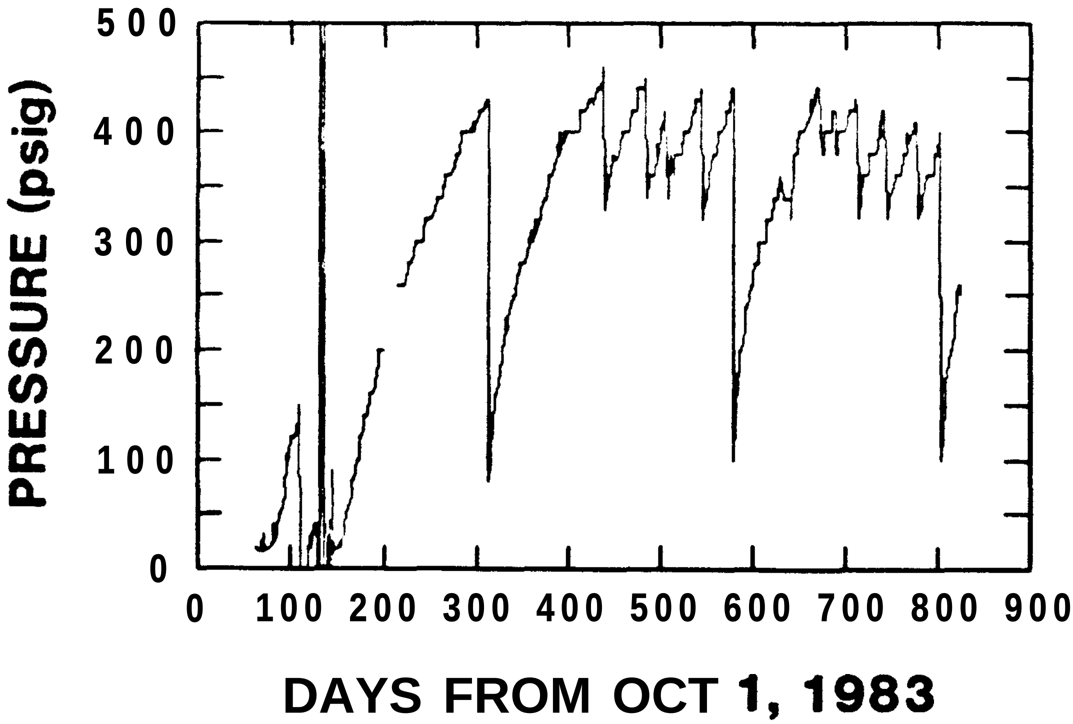


B. Well 109B.

Figure 8. Pressure-Time Histories for Big Hill Wells 109A and 109B. (Wellhead pressures measured in 13 3/8 x 10 3/4-inch annulus.)

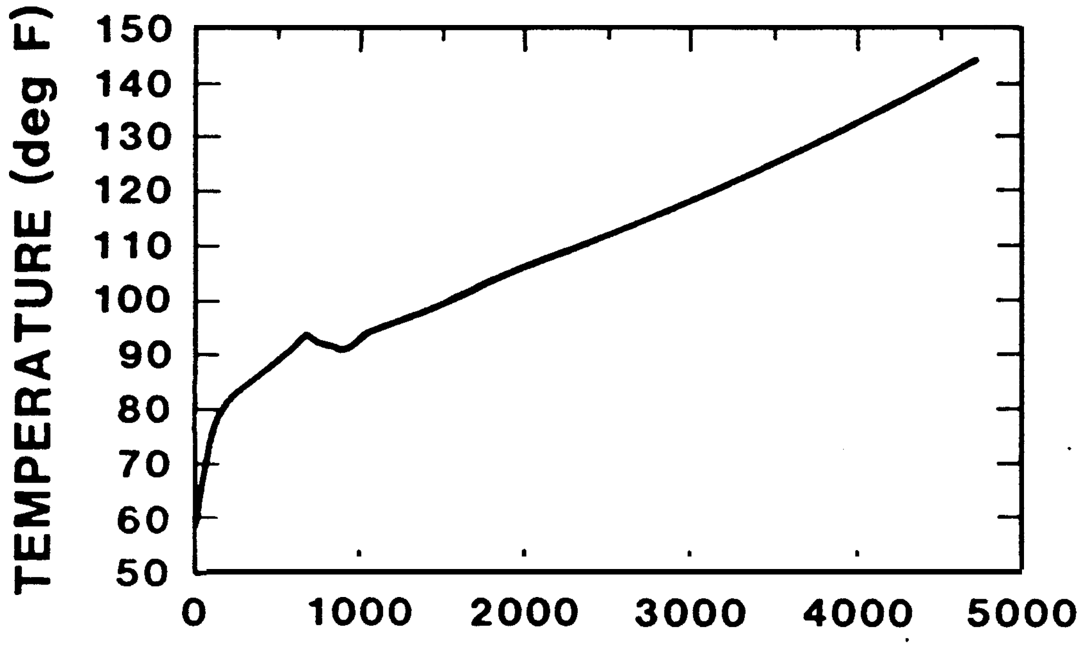


A. Well 110A.

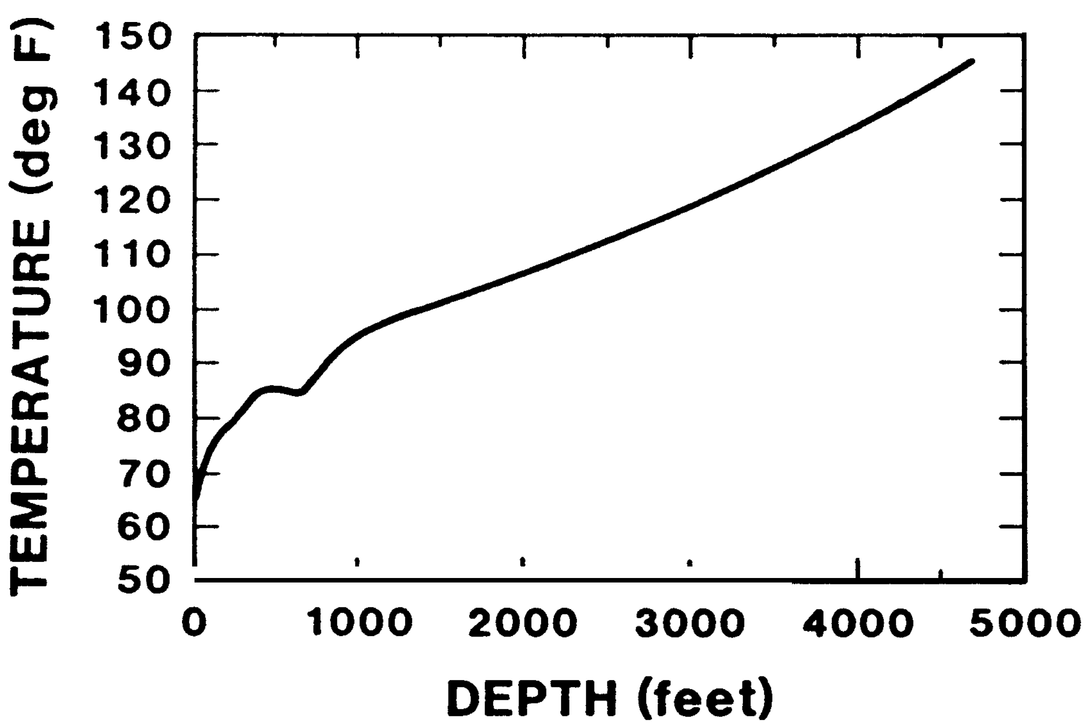


B. Well 110B.

Figure 9. Pressure-Time Histories for Big Hill Wells 110A and 110B. (Wellhead pressures measured in 13 3/8 x 10 3/4-inch annulus.)

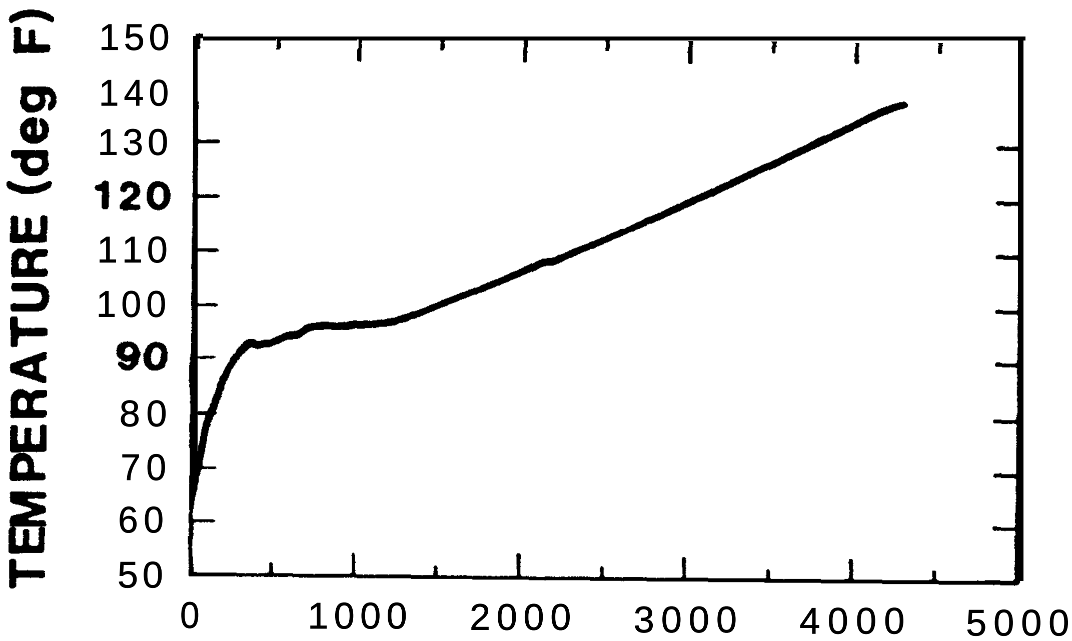


A. Well 106A, February 1984.

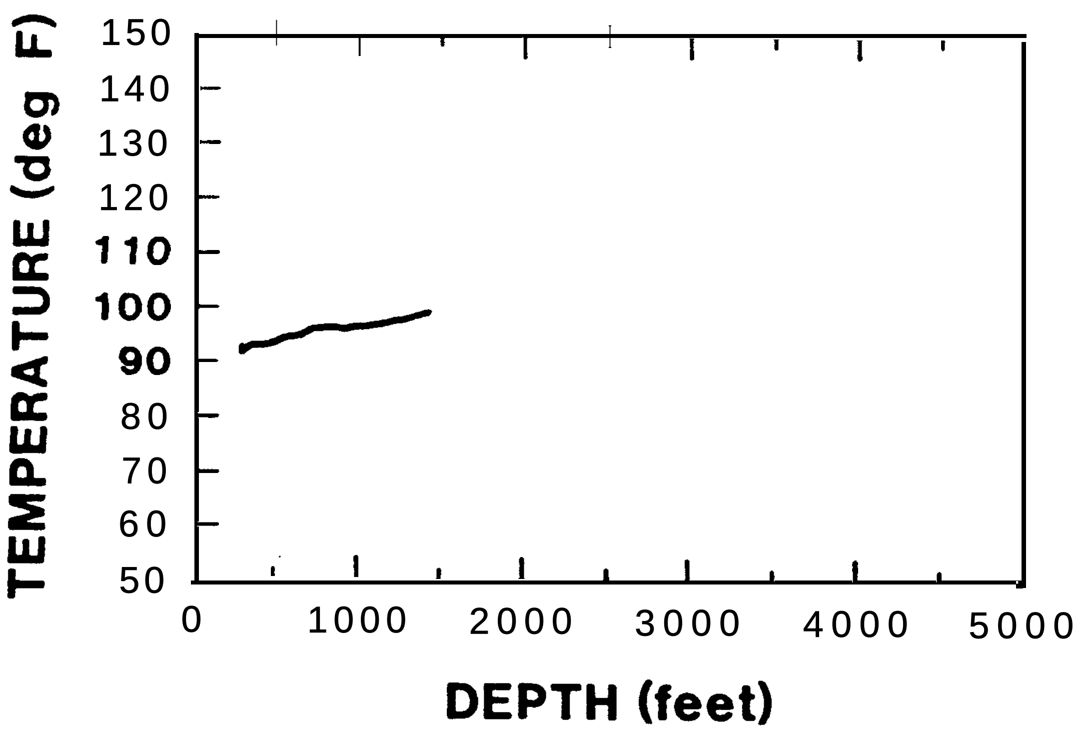


B. Well 110A, February 1984.

Figure 10. Temperature Logs of Big Hill Wells 106A and 110A.

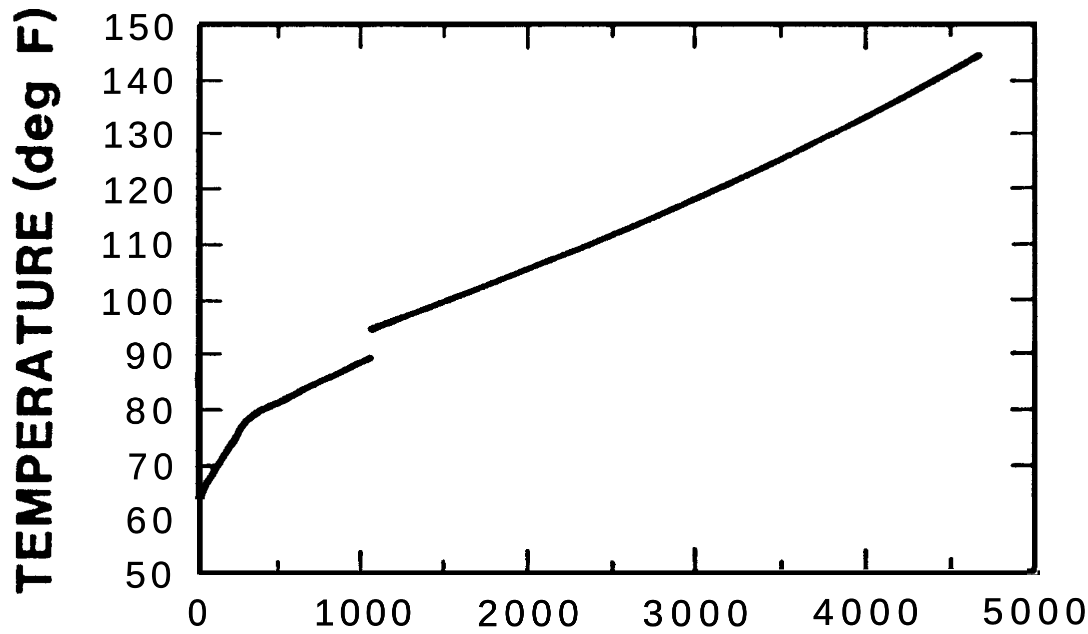


A. Well 107A, February 1984.

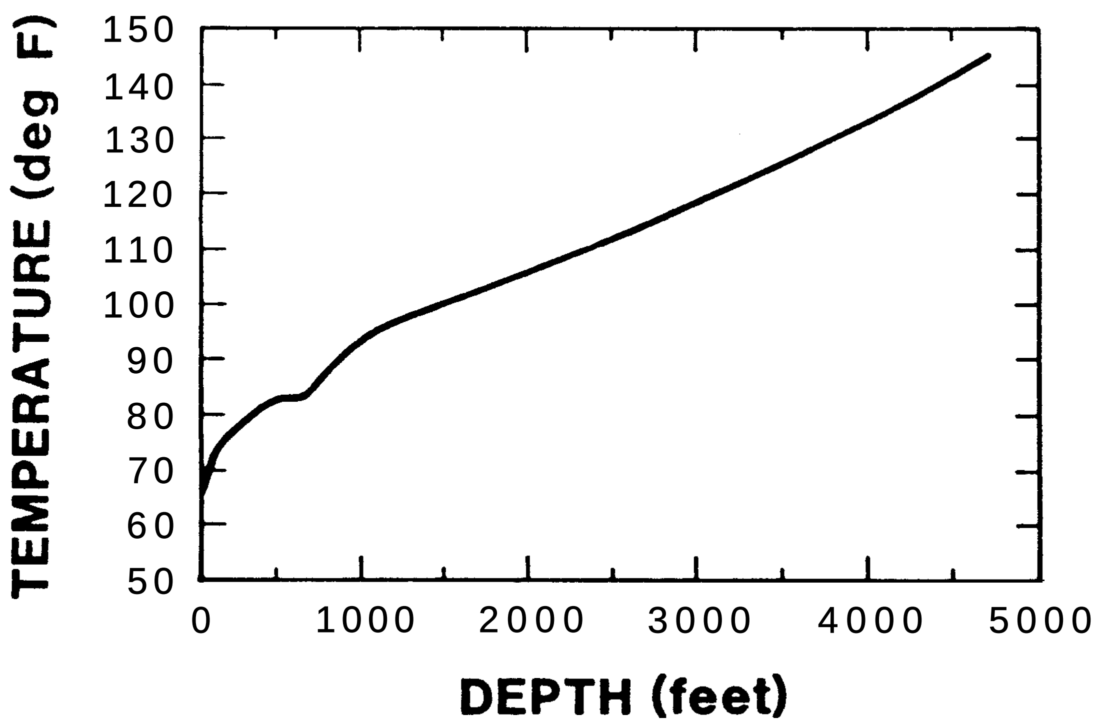


B. Well 107A Re-run, February 1984.

Figure 11. Temperature Logs of Big Hill Well 107A.



A. Well 106B, December 1985.



B. Well 110A, December 1985.

Figure 12. Temperature Logs of Big Hill Wells 106B and 110A.

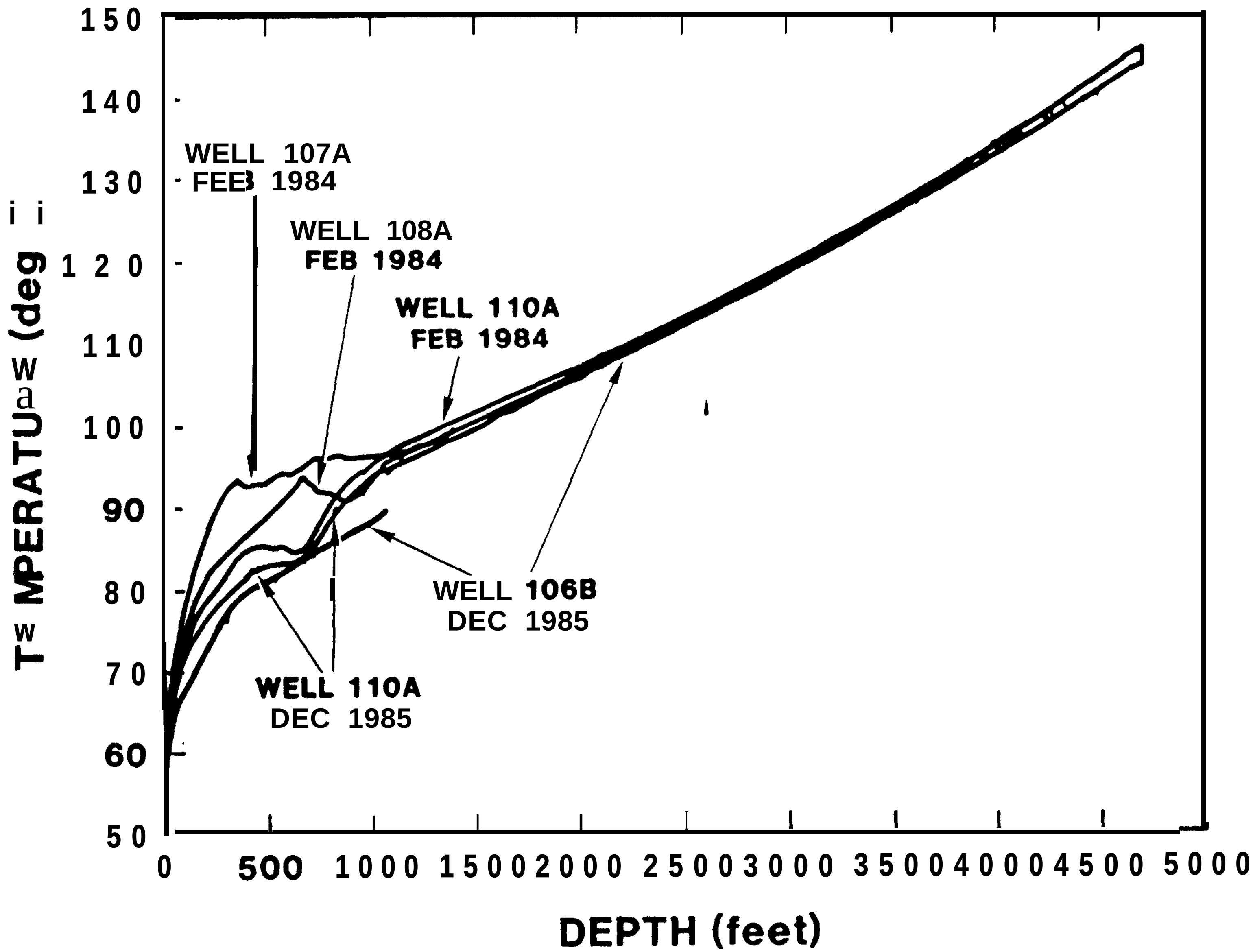


Figure 13. Overlay of Big Hill Well Temperature Logs of Figures 10 through 12.

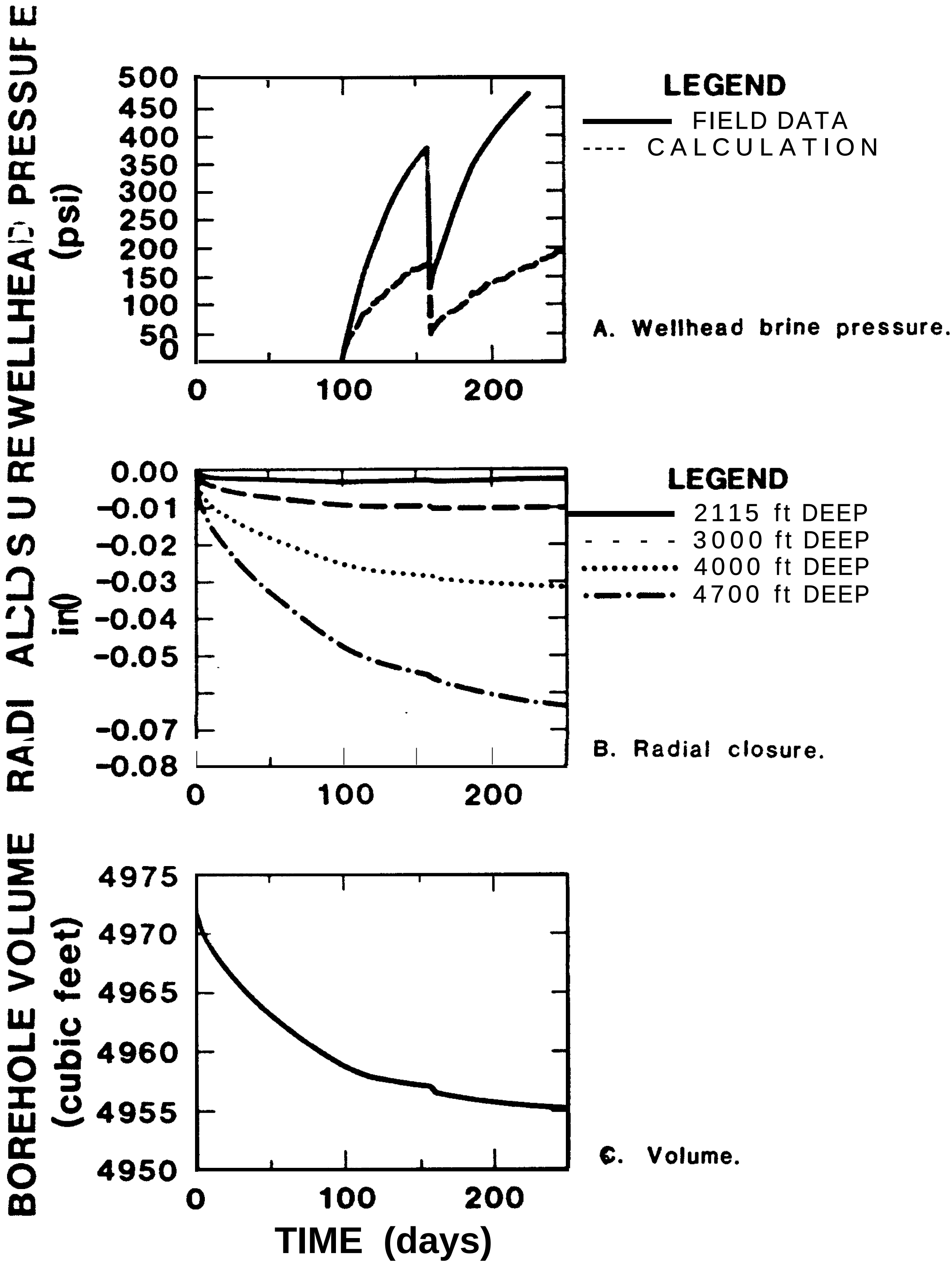


Figure 14. Finite Element Results for Big Hill Well 106B.

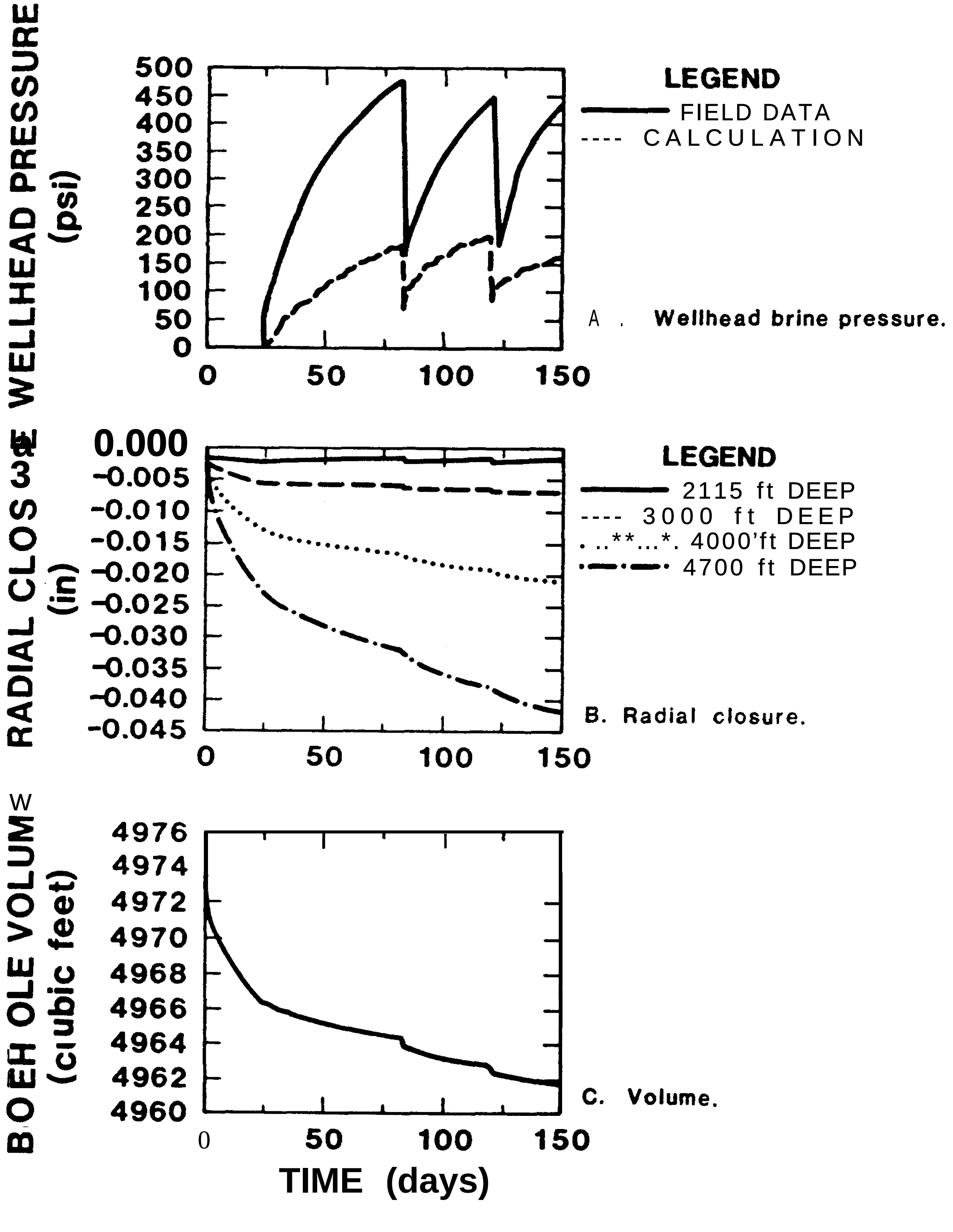


Figure 15. Finite Element Results for Big Hill Well 107B.

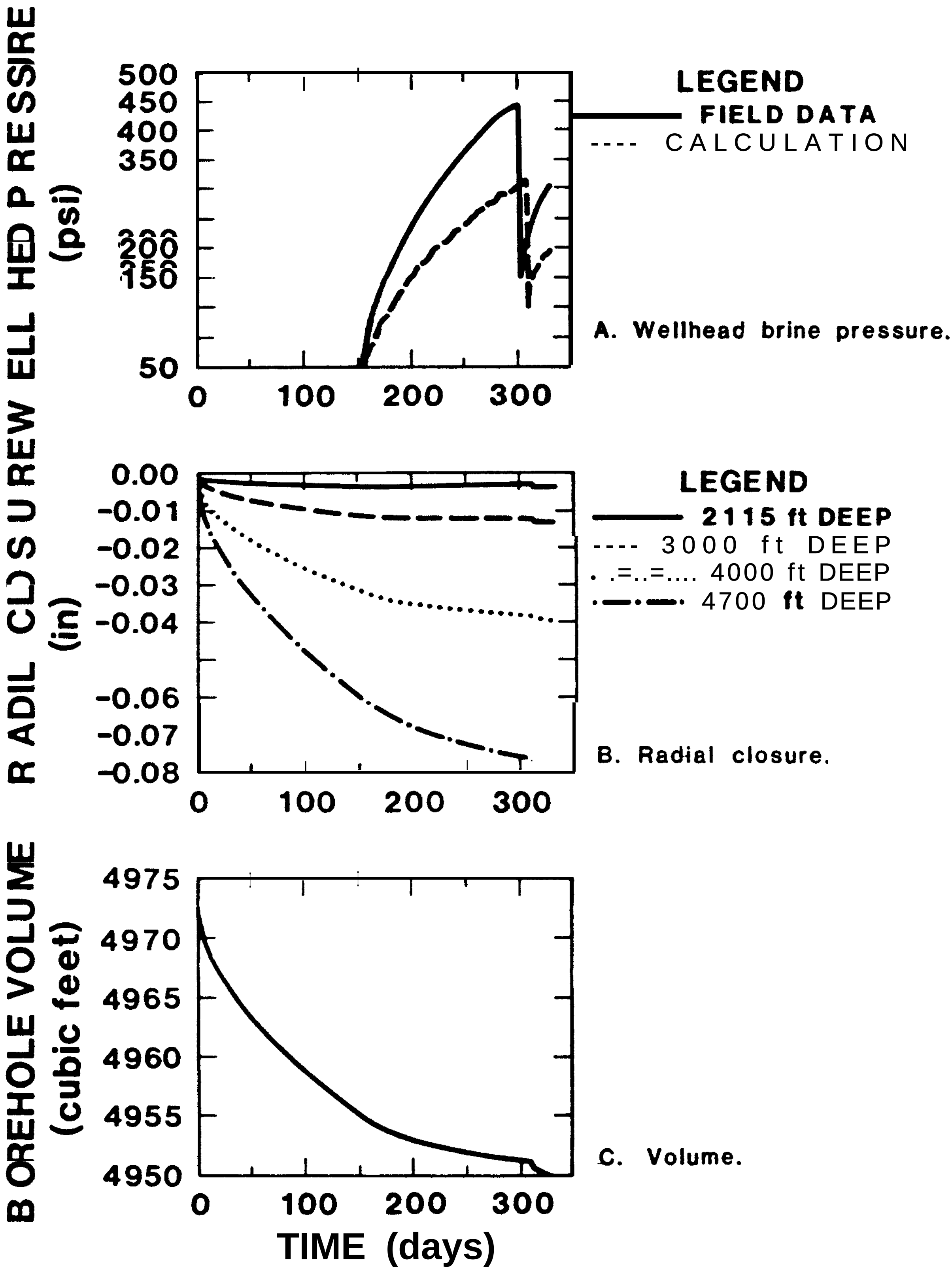


Figure 16. Finite Element Results for Big Hill Well 109A.

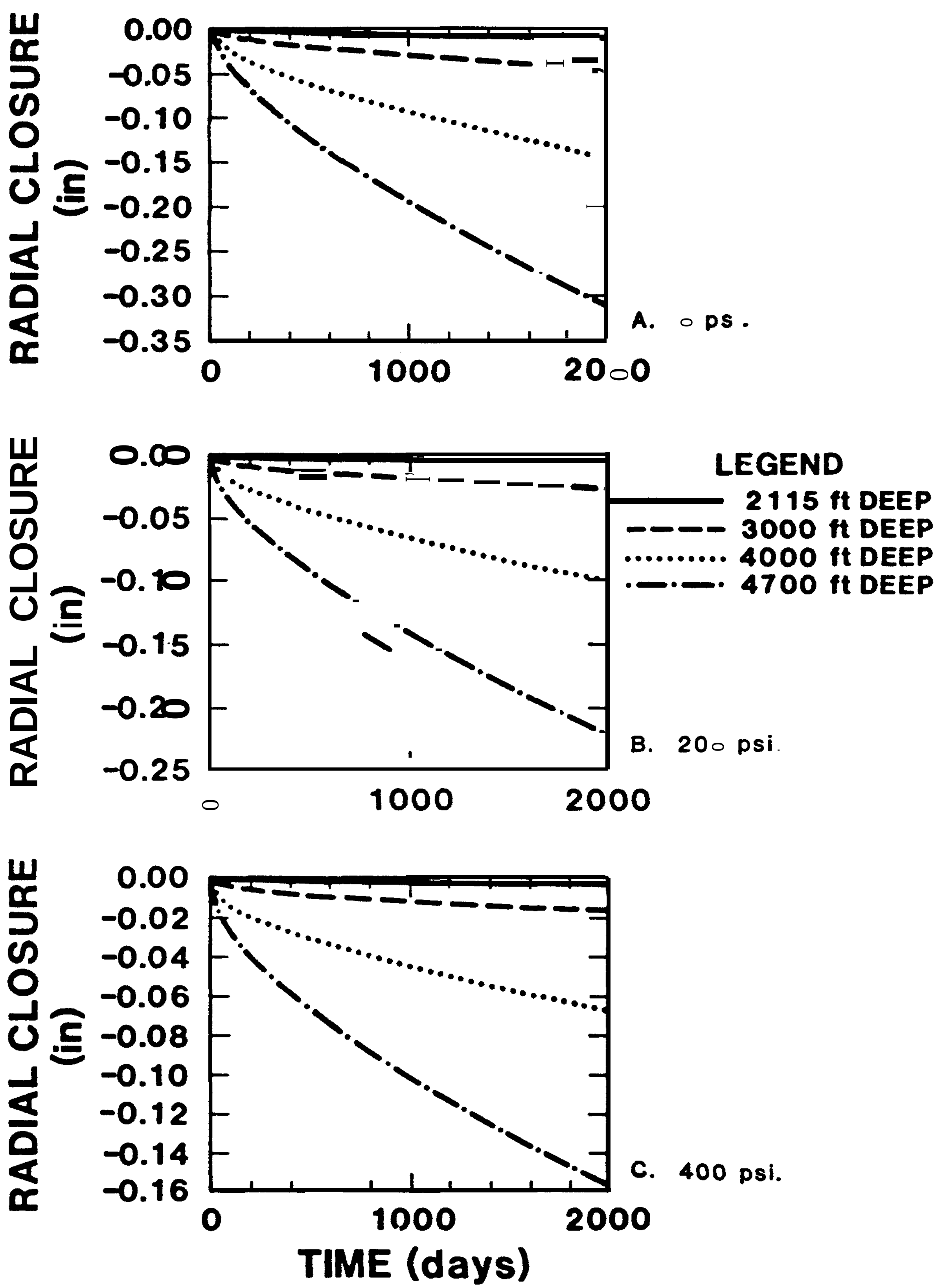


Figure 17. Calculated Radial Closure at Wellhead Brine Pressures of 0, 200, and 400 psi.

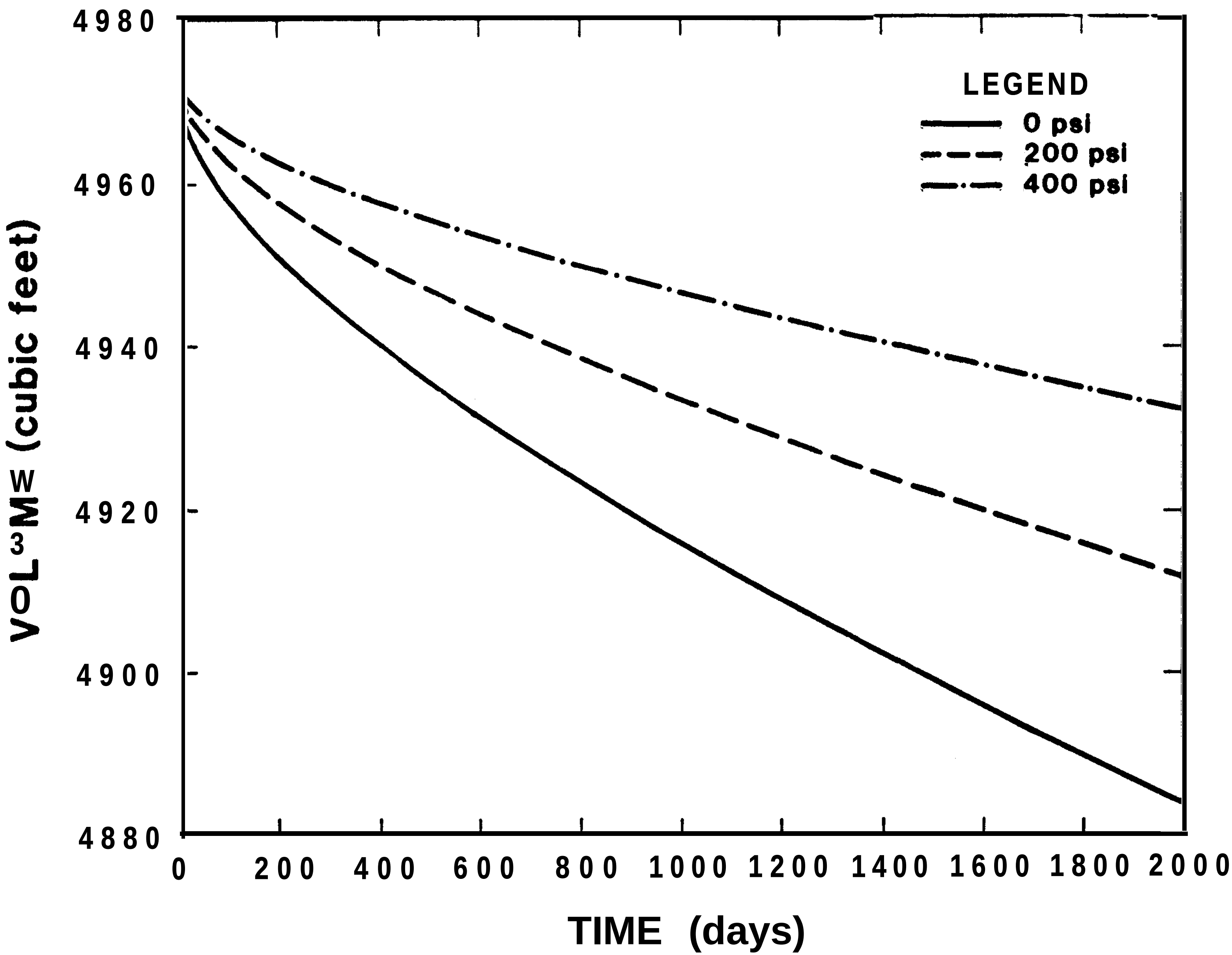
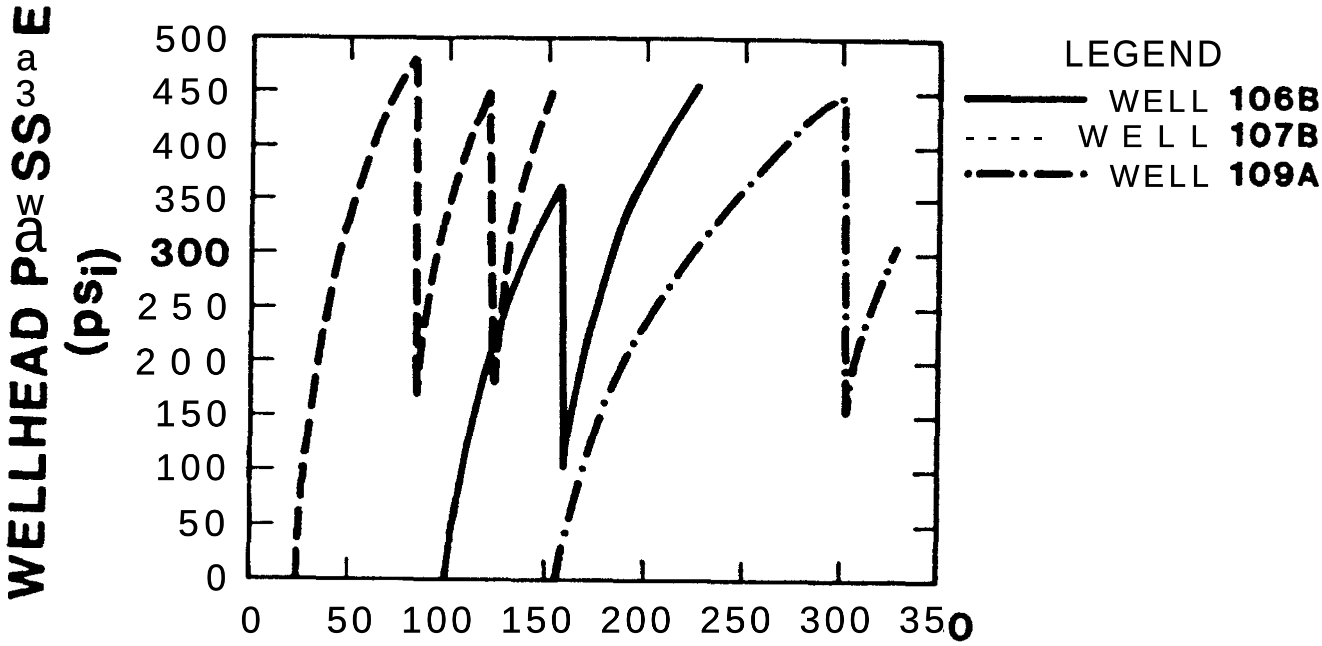
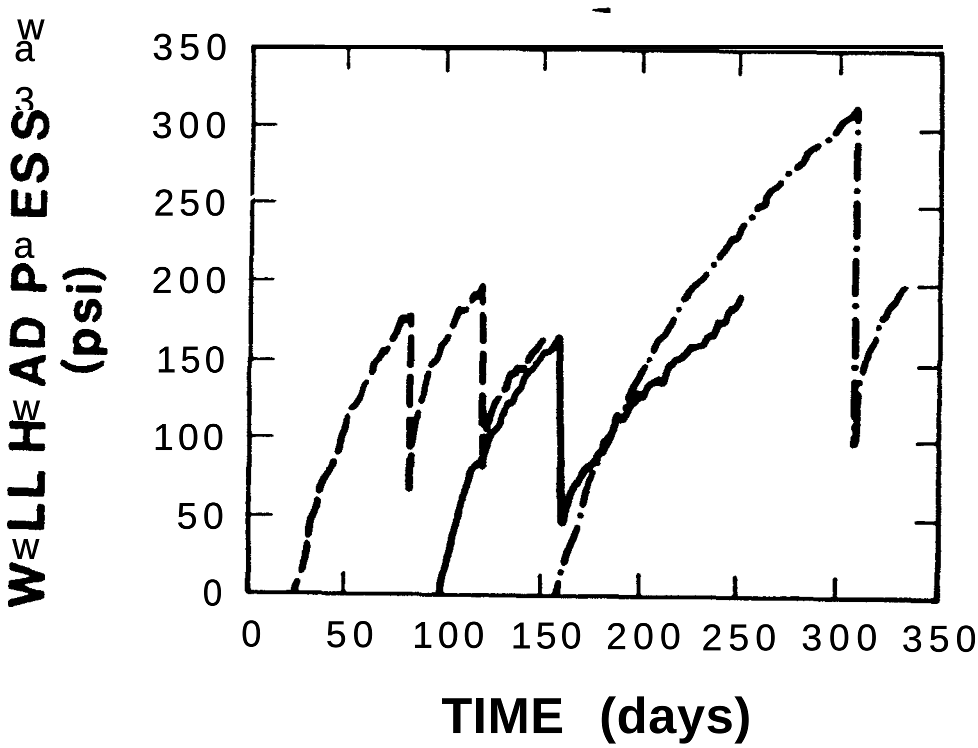


Figure 18. Calculated Well Volume Change at Wellhead Brine Pressures of 0, 200, and 400 psi.



A. Field measurements.



B. Finite element calculations.

Figure 19. Comparison of Early Wellhead Pressure Buildup for Wells 106B, 107B, and 109A from Field Measurements and Finite Element Calculations.

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